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PB-254 550

TWELVE-MONTH EXTENSION SONOMA COUNTY SOLID WASTE STABILIZATION STUDY

EMCON Associates

PREPARED FOR
Environmental Protection Agency

1976

PB 254 550

197084

TWELVE-MONTH EXTENSION
SONOMA COUNTY SOLID WASTE STABILIZATION STUDY

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U.S. ENVIRONMENTAL PROTECTION AGENCY
1976

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BIBLIOGRAPHIC DATA SHEET	1. Report No.	2.	3. Recipient's Accession No.
4. Title and Subtitle Twelve-Month Extension Sonoma County Solid Waste Stabilization Study			5. Report Date 1976 6.
7. Author(s) EMCON Associates			8. Performing Organization Rept. No.
9. Performing Organization Name and Address EMCON Associates 1420 Koll Circle San Jose, California 95112			10. Project/Task/Work Unit No. 11. Contract/Grant No. 68-01-3122
12. Sponsoring Organization Name and Address U.S. Environmental Protection Agency Office of Solid Waste Management Programs Washington, D. C. 20460			13. Type of Report & Period Covered 14.

15. Supplementary Notes

16. Abstracts

This report documents the extension of a study originally performed during a 3-year demonstration project sponsored by EPA and Sonoma County, California. The purpose of the contracted extension is twofold: (1) to investigate the stabilization of solid waste in a sanitary landfill by analyzing leachate, gas, and settlement parameters, and (2) to determine the effect on solid waste stabilization of applying, under various operational modes, excess water, septic tank pumpings, and recycled leachate in a sanitary landfill. This report discusses the data produced through the end of the extension period. Tables and figures following this report summarize the data presented.

17. Key Words and Document Analysis. 17a. Descriptors

Landfill, Leachate, Septic Tank, Water

17b. Identifiers/Open-Ended Terms

Test Cell, Waste Management

17c. COSATI Field/Group

PRICES SUBJECT TO CHANGE

18. Availability Statement	19. Security Class (This Report) UNCLASSIFIED	21. No. of Pages 52
i.	20. Security Class (This Page) UNCLASSIFIED	22. Price 4.50-2.25

USCOMM-DC 14952-P72

This report has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of commercial products constitute endorsement by the U.S. Government.

An environmental protection publication (SW-120C) in the solid waste management series.

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I. INTRODUCTION

The 12-month study for which this is the final report is, strictly speaking, an extension of the 3-year Sonoma County Solid Waste Stabilization Study funded by the EPA under Grant G06-EC-00351. The Third Annual Report[1] issued for that project effectively discusses the data developed during that study relative to the twofold purpose of the project as stated in the introduction to that report. These were:

1. To investigate the stabilization of refuse in a sanitary landfill by analyzing leachate, gas, and settlement parameters.

2. To determine the effect on refuse stabilization of applying, under various operational modes, excess water, septic tank pumpings, and recycled leachate to a sanitary landfill.

The above are taken as the purposes of the extended study as well, with one important addition: the observations of the composite 4-year study are applied through discussion toward improvement of operating procedures at operational landfills. Indeed, the true value of any investigation such as this must lie in practical application to the field it addresses.

For the original 3-year test program, five field-scale test cells were constructed in late 1971 in Sonoma County, California, with general features as presented in Plates 1 and 2. The cells are approximately 18 meters (60 feet) square in horizontal dimensions and 3 meters (10 feet) in depth. The cells were constructed of clayey soils of relatively impervious nature and were instrumented for data collection and for leachate withdrawal and recycle where applicable. The ca. 765 cubic meters (1000 cubic yards) of refuse deposited in each cell was weighed, subsampled for compositional analysis, placed, spread and compacted to a density of ca. 350 kilograms per cubic meter (1000 pounds per cubic yard). Water and septic tank pumpings were added before final covering to Cells B and E, respectively, in quantities sufficient to approximate field capacity of the refuse. Subsequent to final covering, cells C and D received daily applications of water and recirculated leachate, respectively. Cell A, as the control cell, received no moisture beyond that provided by rainfall. Table 1 summarizes the purposes of the cells and the liquid conditioning applied to each.

Over the past 4 years, the leachate, gas, and settlement characteristics of the five cells have been monitored to determine the effects of the various conditioning procedures. This report covers the fourth year of that period, extending the results reported in the Third Annual Report referred to above.

II. SUMMARY

This study was designed to examine the effect of varying operational regimes on the rate of degradation of refuse placed in simulated sanitary landfill field test cells. The five test cells, each containing approximately 765 cubic meters of municipal refuse at a density of ca. 350 kilograms per cubic meter, were constructed in late 1971 and have been operated continuously in the following modes: (1) initial saturation of the refuse with water; (2) daily, uni-directional through-flushing with water; (3) daily leachate recirculation; (4) initial saturation of the refuse with septic tank pumpings; (5) control.

Each of the cells was constructed to allow recovery of any leachate or gas generated and for measurement of settlement. Groundwater monitoring wells were established up and down gradient of the test cells to allow detection of water quality changes attributable to the operation of the test cells. The leachate from each of the cells has been sampled during the last year at six-week intervals; gas and groundwater have been monitored twice, and settlement three times, during the 12-month study period.

The data generated during this study generally show a continuation of trends established during the preceding 3-year study. The marked difference in behavior between the group consisting of Cells A, B, and E (without daily moisture addition) and that consisting of Cells C and D (with daily moisture addition) continued to be evident, indicating a greatly increased rate of refuse degradation when subjected to continual moisture addition.

The parameter levels measured in Cells A, B, and E indicate only slight to moderate waste degradation. The leachate continues to be of high strength characterized by low pH and high chemical oxygen demand, volatile acids concentration, and total dissolved solids. The methane content of gases from Cells B and E, water and septic tank pumping additions respectively, has just recently begun to pick up, indicative of establishment of methanogenic biodegradative mechanisms. Cell A (control) gas continues to be essentially devoid of methane. Settlement of Cells B and E does not significantly differ from that of the control cell, all settling by approximately 7.5 percent of initial refuse thickness.

Cells C and D, daily water addition and leachate recycle respectively, have shown extensive waste degradation as evidenced by the dramatic decline in leachate strength observed in the original study. The present leachates are relatively low in chemical oxygen demand, volatile acids, and total dissolved solids, and have a pH of near neutral. Inorganic ions declined from original levels, but remain high compared to municipal waste water. The gas evolved from these cells continues to show very high methane levels, 65 to 70 percent by volume. The settlement of both of these cells has greatly exceeded that of the other group, with Cell D presently exhibiting a 20 percent decrease from original refuse thickness.

Comparison of the extent of leachate attenuation provided by leachate recirculation through refuse (Cell D) with that achieved in external aerobic and anaerobic processes indicated the processes to be of similar effectiveness. All processes were effective in reducing organic loading and total dissolved solids removal, but did little to diminish the concentration of various inorganic ions (e.g., Cl). The effluent from each of these processes might need further treatment such as by ion exchange or membrane filtration before discharge in certain situations.

Leachate recirculation appears to be promising as a technique for both accelerating refuse decomposition and treating leachate. Suggestions for application of recycle to limited portions of a full-scale sanitary landfill are made in an effort to stimulate thought on the subject.

III. CONCLUSIONS

1. Cell A continues to exhibit leachate, gas, and settlement characteristics consistent with behavior of a typical sanitary landfill. This cell serves as a control cell (no additional moisture management), against which the other cells are compared.

2. Addition of moisture to refuse at time of placement (Cell B) results in some acceleration of the decomposition process. This is evidenced by the increased methanogenic activity presently occurring in this cell relative to Cell A. Leachate and settlement parameters have not demonstrated any significant variation from those of Cell A. Little benefit or harm seems to result from moisture application on placement other than accelerating the production of leachate and methane.

3. Continual flow-through of water (Cell C) results in a significant increase in decomposition and also serves to flush soluble organic and inorganic constituents from the system. Vigorous methanogenic activity and settlement continue. The rate of change of leachate constituent concentration is approaching zero for most parameters. The total mass of certain materials leached from Cell C waste is consistent with that of other leach studies. Cell C mode of operation is not recommended for application to full-scale landfills because of the leachate volume produced. This cell may be representative of response of a fill to high precipitation or surface water inflow and therefore may prove a useful model in these instances.

4. Leachate recycle (Cell D) is an effective method for reducing the organic loading of leachate, less effective in TDS and Kjeldahl nitrogen removal, and minimally effective in inorganic ion removal. The process produces leachate that matches the organic strength of municipal wastewater, but generally exceeds it in other constituents. Generally recycle appears to be as effective as external aerobic or anaerobic ponding with less likelihood of being adversely affected by cold weather. Leachate recycle dramatically increases settlement and therefore the achievement of physical stability of the fill.

5. Addition of septic tank pumpings (Cell E) has resulted in refuse response similar to addition of moisture alone (Cell B). No significant differences have been noted between the two cells. Leachate bacterial loading did not exceed that of other cells, so disposal of septic tank pumpings may be acceptable from a pathogen release point of view. Viruses may be present, however, as test procedures were not designed to detect these life forms.

IV. BACKGROUND TO STUDY

This study, like numerous others, has had as an implicit goal the improvement of techniques for sanitary landfilling of solid wastes. The necessity for studies such as this stems directly from the sheer magnitude of the solid waste disposal problem and the concomitant possibility for large-scale detrimental effects on the environment and to public safety. The United States produces in excess of 115 million tons* of residential, commercial, and institutional waste annually, equivalent to a per capita generation of 3 pounds* per day as of 1968.(2)

The composition of the above waste stream has been found to be reasonably uniform throughout the United States, and has been characterized and reported by the National Center for Resource Recovery(2) as shown on Table 2. The characteristics of the refuse utilized in this study are also presented in Table 2 for comparison. The major portion of the wastes generated (more than 90 percent) are disposed of to the land, the most acceptable procedure being by sanitary landfilling.

Sanitary landfilling has been defined as "an engineered method of disposing of solid wastes on land by spreading them in thin layers, compacting them to the smallest practical volume, and covering them with soil each working day in a manner that protects the environment."(3) These practices are aimed at mitigating potential problems associated with land disposal of solid wastes, such as breeding of vermin and vectors, rapid consumption of site volume, production of odors, and unfavorable visual impact. The landfilling aspects of greatest concern and the most difficult to solve, however, are those associated with the escape of the by-products of refuse decomposition from the site and the effect these substances have on the land-water-air environment and on public health. Since most problems associated with sanitary landfilling are coupled in some manner to decomposition of the wastes placed within a landfill, a knowledge of these degradative processes becomes essential to effective operation of this form of waste disposal. The mechanisms of decomposition are of such fundamental importance to interpretation of study findings that a synopsis provides an effective foundation for data presentation and discussion of findings.

Synopsis: Refuse Decomposition in a Typical Sanitary Landfill Environment

The mechanisms of municipal waste decomposition have been described in varying detail in numerous studies, including the precursor to this one. Generally it can be said that a large portion of the solid wastes placed in sanitary landfills undergo biologic and chemical transformation to produce solid, liquid, and gaseous by-products. Substances such as fats, proteins, and carbohydrates (e.g., cellulose, starches) are degraded into progressively less complex compounds by multi-stage aerobic and anaerobic microbial metabolic processes. Typical intermediate compounds produced or liberated are organic acids (including both volatile and non-volatile fatty acids), inorganic ions, carbon dioxide (CO_2), water

*These figures do not include agricultural, mining, or industrial waste.(2)

(H_2O), ammonia (NH_3), and others. Certain of these substances are utilized in turn by other microorganisms which produce methane (CH_4), CO_2, H_2O, hydrogen sulfide (H_2S), and other simple compounds. Inorganic ions are released during waste degradation, the solubility of many being enhanced by the low pH found in landfills undergoing active degradation. When most of the biodegradable material in the landfill has been consumed, the refuse reaches a state of stabilization characterized by minimal biological activity and a resultant low rate of production of gaseous and soluble metabolic by-products.

Typically, refuse placed in a landfill will undergo an initial relatively short phase (days to weeks) of aerobic (oxygen-requiring) decomposition, followed by an extended period of anaerobic (oxygen-free) degradation. The anaerobic processes are the more important because rapid consumption of the molecular oxygen trapped on refuse placement and lack of reintroduction mechanisms serve to limit the duration of aerobiosis. Further discussion will therefore concentrate on anaerobic degradation.

The early anaerobic biodegradation processes are dominated by organisms employing acid fermentation type metabolism and yielding volatile fatty acids, ethanol, a large number of inorganic ions (e.g., Cl^-, SO_4^{-2}, Ca^{+2}, Mg^{+2}, Na^{+2}) and a gas composed almost totally of CO_2. In this stage pH generally falls (ca. 5) because of volatile fatty acid accumulation as well as the high partial pressure of CO_2. This stage is followed by one in which bacteria utilizing methane fermentation metabolism predominate. These methanogenic bacteria are strict anaerobes (oxygen at any detectable level being extremely toxic) and in general are slow-growing and have tight pH tolerances (6.6 to 7.4). The substrates for methane formation by different species of methanogenic bacteria have been given as $H_2 + CO_2$; formic, acetic, and butyric acids; and ethanol and methanol. These substrates are made available from the refuse material by the various precursor aerobic and anaerobic microbial populations.

The activity and very existence of a microbial population depends on a multitude of abiotic factors, especially moisture, gases present, and pH, with a favorable range of values usually being definable for each factor. The maximum and minimum values are physiological limits beyond which the microbial population in unable to maintain itself or to perform a vital function. For many factors an optimal level or range can be established, in addition to upper and lower limits. The refuse moisture content, for example, has an important role in promoting stabilization by decomposition. It is not possible at this point to quantitatively state what a minimum or optimum moisture content might be, but generally speaking, the more moisture, the higher the rate of decomposition.[4] The sensitivity of methanogenic bacteria to pH and O_2 have already been mentioned.

Certain data seem to contradict this concept of physiological limits, particularly in those instances where a cell or landfill simultaneously produces methane and leachate with a pH well below the minimum necessary for survival of methanogenic bacteria. This can be explained as follows. In a heterogeneous mixed-media system such as is found in a

landfill, it is to be expected that many environmental conditions will occur concurrently in different loci, resulting in the formation of separate microenvironments wherein quite different types of organisms may grow. Therefore, it is not surprising to find methane produced in a landfill which appears from its leachate to have a pH of 5 (even though methanogenic organisms cannot exist at pH 5), because pockets or regions (microenvironments) can exist in the landfill where conditions allow these organisms to survive.

Refuse Decomposition and Its Potential Environmental Impact

As previously stated, the majority of the problems associated with sanitary landfills result from degradation of the waste. Were the by-products of waste decomposition to be restricted to the body of the landfill, then most of these operational difficulties would be solved. In many instances, however, groundwater or surface waters infiltrate the refuse mass and form a solution containing many of the organic and inorganic compounds formed by waste degradation. If this solution leaves the refuse mass, it is termed leachate. This leachate can seriously impair the quality of any groundwater or surface water it contacts. The gases produced (primarily CH_4 and CO_2) can also migrate from the fill. Methane is flammable in certain concentrations and thus can pose a threat to public safety. Methane can cause an explosion if it accumulates in an enclosed area and is ignited. Carbon dioxide is readily soluble in water, forming an acidic solution with a resultant increase in the aggressive nature of the water and the quantity of minerals that can be carried in solution. Another consequence of breakdown of the waste in a sanitary landfill is a reduction in bulk and the collapse of voids in the refuse, causing settlement of the landfill surface which affects the utility of the site for end usage.

The period during which a landfill undergoes active degradation ranges from perhaps ten to hundreds of years, the time being dependent primarily on the moisture content of the refuse. Thus, the problems associated with any given landfill are likely to continue far beyond the termination of refuse placement, and indeed may not appear for some time after fill completion. Post-construction maintenance and care of a completed landfill site to assure that it maintains its integrity and does not become a source of pollution can therefore be a long-term source of concern. If the rate of landfill degradation could be accelerated so that the processes that normally might take 50 years could be accomplished in 5, the period during which a completed landfill must be cared for is reduced significantly. Also, an enhanced rate of degradation means that associated effects such as settlement are also accelerated, perhaps allowing the end usage of the site to be implemented quickly and with fewer operational problems.

V. PROCEDURES AND RESULTS

This section describes the experimental procedures utilized throughout the study, and presents the results obtained.

Leachate: Samples of the leachate generated by each of the cells were collected at six-week intervals during this study, utilizing procedures described in Appendix G of Reference 1. The samples were analyzed for the chemical and physical parameters presented in Table 3. Sample analyses were accomplished in general accordance with APHA Standard Methods[5] with modifications where necessary. Further information regarding analytical techniques for leachate can be found in References 6 and 7. The data developed during the present effort are presented in Tables 4 through 8 and graphically in Figures 1 through 17. The figures also present 6-month means for data collected in the previous 3-year study to allow evaluation of current data in a historical perspective. Certain additional leachate components were quantified during the original study, and the reader is referred to previous reports for details.

Gas: Samples of decomposition gases were collected from probes located within each cell and analyzed by gas-solid chromatography for percent (by volume) of carbon dioxide (CO_2), nitrogen (N_2), oxygen (O_2), and methane (CH_4). The instrument was calibrated utilizing a known gas mixture of CH_4, N_2, and CO_2, accurate to better than one tenth of a percent by volume. On occasion, gas samples were obtained with relatively large concentrations of O_2 and N_2 from probes sampling deep within a cell. The O_2 content is assumed to be atmosphere derived and due to leaks in the probe tubing allowing entry of air. The O_2 and N_2 content were particularly suspect if present in a ratio of 1:4 (atmosphere ratio). The analyses showing the suspected air contamination were corrected by removal of all O_2 and of N_2 equal to O_2 volume times 4, the corrected values being presented with other gas analytical data in Table 9. The corrected compositions are also presented graphically in Figures 19 and 20.

Settlement: Surface settlement of each of the cells relative to fixed bench marks has been monitored periodically since refuse placement. Settlement is taken as the mean variation in elevation of 5 monitoring plates permanently emplaced on each cell. The settlements exhibited by the cells are shown in Figure 18 expressed as percent of the original refuse thickness of 244 cm (8 feet). The cover was assumed to remain at constant density and therefore to not contribute to settlement.

Other: Groundwater quality observation wells are installed at locations shown in Plate 1. The water in these wells has been monitored twice during the present study for electro-conductivity, pH, dissolved oxygen, temperature, and water level. These data are summarized with values obtained upon project commencement in Table 10. During various portions of the previous 3-year study, additional data were collected on internal cell temperatures, water quality in lysimeters located in the soil beneath each cell, site precipitation, evaporation, runoff, and liquid flow into and from the various cells. These data can be found in the reports issued under the original study.

VI. DISCUSSION OF RESULTS

The following discussion is organized to address the objectives of the project, which were:

1. To investigate the stabilization of refuse in a sanitary landfill by analyzing leachate, gas, and settlement parameters.*

2. To determine the effect on refuse stabilization of applying, under various operational modes, excess water, septic tank pumpings, and recycled leachate to a sanitary landfill.

3. To apply the information gained in the composite 4-year study toward improvement of operational procedures at full-size sanitary landfills.

Also, conclusions and discussions presented in the Third Annual Report submitted under G06-EC-00351 generally are applicable to the data developed during the present study, as trends and observations cited therein have shown continued validity.

Quantification of Landfill Stabilization by Analysis of Leachate, Gas, and Settlement

From the discussion of refuse decompositional mechanisms presented in the Background section of this report, we can see that various substances are characteristic of the differing types of microbial metabolism occurring in a decomposing refuse fill. The processes are complex, with multitudinous interactions, but for use here they can be generalized to a sequential process wherein the heterogeneous microflora present in a landfill are progressively varying in species composition as the landfill environment changes. One group of bacteria degrade certain compounds to simpler entities which are in turn utilized as substrates by another group. This continues until the by-products produced are incapable of supporting further biological growth. Many of the compounds produced at varying points in this continuum of substance transformation are either soluble in water or evolved as gases. It should be possible, therefore, to deduce the relative location of a landfill along the path of degradation by measuring the concentrations of these by-product substances. This type of analysis was accomplished in some detail on a cell-by-cell basis in the discussion section of the Third Annual Report of the previous study, and will only be slightly extended here. Comments are separated into two categories, those pertaining to Cells A, B, and E, and those to Cells C and D. The differences of response between the ABE group (without daily moisture addition) and the CD group (with daily moisture addition) are considered to be of greater significance than cell-to-cell variations within either group.

Cells A, B, and E: Cells A, B, and E continue to show levels of all leachate parameters indicative of slightly to moderately degraded waste (see Tables 4-8 and Figures 1-17). The graphs of parametric concentrations indicate that leachate component levels may have reached peak mean

*This section also includes a discussion of groundwater monitoring data.

values (when corrected for seasonal fluctuations) between mid-1973 and mid-1974, and may gradually be moving generally lower. The gas composition of Cells B and E indicates that methanogenesis is becoming increasingly important. Further evidence of the state of degradation in these cells was derived from the composition of leachate by computation of linear correlation coefficients for various paired variables.

The leachates from Cells A, B, and E show correlation coefficients in the .70 to .90 range for most paired variables examined. These cells show a relatively high correlation of total dissolved solids (TDS) with sulfate, chloride, and iron, and a low correlation of TDS with biochemical oxygen demand (BOD), indicating inorganic species to be an important conponent of TDS residues. A low correlation of total Kjeldahl nitrogen to volatile acids indicates that a large portion of the nitrogen-containing organics (e.g., proteins) have yet to be degraded to small fragments (e.g., amino acids, volatile fatty acids).

It is likely that a significant portion of the large-scale, long-term changes in level of many of the components in Cells A, B, and E leachates is due to environmental influences affecting the dilution or concentration of the leachates. Cell A seasonally exhibits an upward movement of nearly all parameters as the leachate flow rate undergoes its annual summer decrease. Cell A leachate parameters of 6/27/75 relative to those of 2/19/75 indicate a reasonably uniform 2.7 times increase across the board. This is most readily explained by evaporation or other mechanisms causing an overall increase in leachate concentration by approximately three times. Evaluation of correlations for Cells A, B, and E, therefore, must also take into account the influence of such parallel trending.

Methane concentrations in the gas evolved by Cells B and E have shown an increase from levels observed during the previous study, to 18 and 20 percent respectively, with that of Cell A continuing to remain low at ca. 1 percent. Cells B and E appear to be entering the methanogenic phase of degradation and leaving the control Cell A as the only fill to continue in non-methanogenic anaerobiosis.

Surface settlement continues as previously. Cells A, B, and E have shown a mean settlement of 18.6 cm (0.61 feet) or 7.6 percent of the original 244-cm (8-foot) refuse thickness. The settlement characteristics are consistent with the general trend of data, indicating the wastes of Cells A, B, and E to be undergoing decomposition at a relatively slow rate. The concentration of fecal coliform in the leachate for these cells continues to be low, while fecal streptococci have demonstrated erratic fluctuations (2/3/76).

Cells C and D: Both Cells C and D have succeeded to a large extent in rapidly and effectively decomposing refuse with a concomitant production of low-strength leachates. This is graphically indicated by the trend of most parameters in Figures 1 through 17. Cell D, which generally shows the greatest degree of degradation and lowest-strength leachate, has accomplished this without discharge of leachate from the system. The time variation of the quality of leachate from Cell D corresponds well with that derived from Percolation Bin No. 1 in Reference 8, an 18-month water application study. Cell C has produced and discharged in

excess of 2 million liters (525,000+ gallons) of leachate, all of which has either been disposed of by evaporation or injection into an adjacent landfill.

Reflective of the differing leachate character between Cells C and D and Cells A, B, and E are the relative contributions of inorganic versus organic species to the total dissolved solids (TDS) load. In contrast to Cells A, B, and E, high correlations were found in both Cells C and D between total Kjeldahl nitrogen (TKN) and biochemical oxygen demand (BOD), volatile acids (VA) and BOD, and TKN and VA, indicating that these cells have degraded much of their organic matter to short-chain organics, some of which are nitrogenous and may be amino acids. That these components also make up the major portion of the TDS load is demonstrated by high correlations of both TKN and VA to TDS. That TDS is not highly influenced by other likely substances is shown by the low correlation of TDS with nitrate (NO_3), chloride (Cl), sulfate (SO_4), and iron (Fe). The presence of nitrate, sulfate, and iron in TDS is highly dependent on the oxidation-reduction state of the leachate, and will vary in response to changes in redox potential. The reduction in SO_4 evident in Cells B, C, D, and E, Figure 14, may be indicative of enhanced reducing conditions. Also, correlations of both BOD and TKN to alkalinity indicate the organic compounds that contribute to BOD may be important proton acceptors.

Methane concentrations in the gas evolved by Cells C and D have reached concentrations of 70 and 66 percent by volume respectively (see Figure 19 and Table 9). Carbon dioxide concentrations are approximately 30 percent for both cells (Figure 20). Surface settlement for Cell C continues as previously, but Cell D has exhibited a dramatic increase (see Figure 18). Cell C shows a cumulative settlement of 30.8 cm (1.01 feet) or 12.6 percent of initial refuse thickness. Cell D has settled 49.4 cm (1.62 feet) or in excess of 20 percent. The large difference between Cell C and Cell D is inferred to be indicative of the greater degree of decomposition that has presumably occurred in the latter. The difference in settlement characteristics effectively rules out the mere existence of high liquid flow rates as the predominant mechanism accounting for the enhanced biological activity of Cells C and D relative to A, B, and E. Leachate recirculation apparently is more conducive to high rate biodegradation of wastes than simple saturation of the wastes. Fecal coliform counts continue to be low for both cells, while fecal streptococci show apparently random, multiple order of magnitude fluctuations of unknown cause.

The effectiveness of recirculation in reducing the mass of various soluble constituents released to the environment can be assessed by comparison of Cell C with Cell D. The mode of operation of Cell C should allow an estimate to be made of the mass of a given component that might ultimately be leached from refuse undergoing decomposition. This hypothesis is based on the assumption that all leachable substances exit the cell in solution via the collection system with its associated flow meter. The cell undergoes uni-directional flow, and it is assumed to have a sufficient volume of water flushed through with uniform distribution so as to allow solution of the majority of species capable of leaving the system in this manner. Utilizing a mean concentration for

each parameter over the project life, and a total leachate production of approximately 2,000,000 liters, the cumulative output of Cell C for several components has been the following:

COD - 24,000+ kg of O_2 demand	TKN - 600+ kg
Cl - 950+ kg	SO_4 - 350+ kg
Fe - 500+ kg	TDS - 11,500+ kg

The effectiveness of Cell D mode of operations is shown by the fact that if a volume of water equivalent to that which has passed through Cell C were to be flushed through Cell D with the present leachate concentrations, cumulative output for the above parameters would be as follows:

COD - 750+ kg of O_2 demand	TKN - 400+ kg
Cl - 1,000+ kg	SO_4 - 30+ kg
Fe - 90+ kg	TDS - 6,400+ kg

Apparently BOD has undergone a reduction of 95 percent, chloride not at all, iron by 80 percent, TKN by 30 percent, SO_4 by 90 percent, and TDS by 45 percent.

The performance of Cell C compares well with the conclusion in Reference 8 that continuous leaching of 370,000 kilograms of refuse (assuming 1245 m^3 @ 300 kg/m^3 (one acre-foot @ 500 lb/yd^3)) would release a minimum of 1365 kilograms (1.5 tons) of sodium plus potassium, 910 kilograms (1.0 tons) of calcium plus magnesium, 830 kilograms (0.91 tons) of chloride, 210 kilograms (0.23 tons) of sulfate and 3545 kilograms (3.9 tons) of bicarbonate. Summation of the above gives a predicted total release of 6855 kilograms of material or 0.018 kilogram per kilogram refuse. Assuming the data to represent <u>total constituent</u> analyses, as was done in this study, and the above listed constituents to make up the major portion of the total dissolved solids (TDS) content of leachate, we find good correlation with the total TDS removed from Cell C. Cell C has leached a total of 11,500 kilograms of TDS from the 474,550 kilograms of refuse placed in the cell, or 0.024 kilogram TDS/per kilogram refuse.

The mass of COD, Cl^- and TKN removed from Cell C when expressed as mass constituent per mass dry refuse exceeded the measurements of the content of these components in refuse utilized by Fungaroli.[9] The results of the two studies are given below in kg component per kg dry refuse.

Component	Cell C	Ref. 9
COD	9.0×10^{-2}	4.3×10^{-2}
Cl	3.5×10^{-3}	9.7×10^{-4}
TKN	2.2×10^{-3}	1.3×10^{-3}

The similarity of refuse composition utilized in the above two studies is shown in Table 2.

<u>Groundwater Quality</u>: Monitoring of groundwater, Cells A and E subdrains, and water added to Cell C shows values of water quality parameters

consistent with those obtained during the original 3-year study. Table 10 shows the results of the two water quality analyses conducted during this study, as well as the mean values obtained during 1972, the first year of monitoring. The sole potentially significant development evident in the data is the increase in the electrical conductivity and decrease in pH measured in water taken from Well 2, downgradient of Cells A and E, in the final sampling on September 30, 1975. These data, should the trend continue, would suggest that ionic species have entered the groundwater table from Cell A, Cell E, or both. If loss of leachate is indeed occurring, it most probably results from direct connection of the cell interior with the groundwater due to lack of adequate sealing of one of the sand lenses encountered during cell construction.(1) This hypothesis might also be supported by the continued year-round production of leachate by Cell A, albeit at varying seasonal rates, and an observed progressive decrease in flow from the A and E groundwater subdrains, both possibly a result of short-circuiting of groundwater flow through the cell. It is unlikely that leachate is exiting the cell through the clay barrier.

Determination of the Effect of Varying Operational Modes on Refuse Stabilization

The principal thrust of this and the previous project was to determine the effect, if any, of operating otherwise comparable field-scale test landfills under differing modes including: (1) one-time saturation of the refuse with water, (2) daily uni-directional through-flushing with water, (3) daily leachate recirculation, (4) one-time saturation of the refuse with septic tank pumpings. The findings presented in the Third Annual Report have continued validity at this time and are therefore presented here in amended and augmented form. The bases for these findings are contained in the discussion of that report and the reader is referred to that source in addition to data and discussion presented herein.

1. Control Cell A shows time dependence of leachate and gas composition consistent with general behavior of typical sanitary landfills. This cell provides a comparative standard for the four managed cells.

2. The addition of moisture to refuse (to approximate field capacity) in Cell B has accelerated decomposition processes to an observable degree, as evidenced by its present enhanced methanogenic activity relative to Cell A. Bringing the landfill materials to field capacity immediately after placement accelerated the development of leachate and presumably has enhanced biodegradation processes even though not observed during the duration of this study in terms of leachate quality. No significant increase in the rate of settling of fill material relative to Cell A was observed.

3. Continual flow-through of water in Cell C has served to accelerate the stabilization of refuse materials, flush out soluble materials, and increase the rate of settlement of fill material. The inorganic solutes and organic solutes have been reduced dramatically. Production of methane began early in this mode of operation and continues at a high rate.

4. Recirculation of leachate through the landfill material in Cell D significantly enhanced the establishment of an active anaerobic microbial population within the fill. The recirculation of leachate has particularly increased the rate of biological stabilization of the organic fraction of the refuse, as evidenced by large reductions in BOD and COD. Inorganic species have also shown significant reductions in most cases. Leachate recirculation essentially uses the landfill volume as a generally uncontrolled anaerobic digestor for effective treatment of its own leachate. The rate of surface settlement has been greatly accelerated for the recycled leachate mode of operation, with latest results (2/3/76) perhaps indicating that maximal settlement is being approached (Figure 18).

5. Seeding of refuse placed in Cell E with septic tank pumpings without additional management accelerated acid fermentation processes, thereby facilitating establishment of anaerobic microbial activity, but appears to have retarded development of vigorous methanogenic organisms relative to Cell B. Leachate composition and settlement show little significant variation from Cell A.

Application of Study Findings to Operation of Full-Scale Sanitary Landfills

Sanitary landfills can continue to be a source of concern after termination of refuse placement, with production of high-strength leachate, migration of methane, and surface settlement presenting the greatest difficulties. Because of the long time over which degradation occurs in a normal landfill, mitigatory measures addressing these areas must often be maintained for many years after site operations are completed. It is conceivable that a landfill operator might be required to collect and treat leachate, operate a gas migration control pumping system, or postpone development of the site for the highest possible end use because of projected continuing large-scale settlement. The necessity for leachate and gas control and the concern with settlement could possibly continue for decades. The response of Cell D to leachate recycle holds promise that the period during which those problems are significant could be shortened, perhaps to less than 5 years after refuse placement. The potential benefits are evident and worth pursuing if leachate recycling can be applied, even limitedly, to a landfill.

Leachate Treatment: The constituents of landfill leachate can affect the quality of receiving water in several ways. The organic and inorganic nutrient substances present can increase the biomass of the receiving system by stimulating growth with a resulting acceleration of the rate of eutrophication. The inorganic salts add to the mineralization and hardness of the system. Toxic substances may inhibit the growth of certain organisms and render the water unfit for various uses. Pathogens might be carried from the refuse, posing a health hazard. One study[8] concluded that escape of leachate from a sanitary landfill could "cause the groundwater in the immediate vicinity . . . to become grossly polluted and unfit for domestic or irrigational use." Landfill leachate obviously must not be allowed to enter usable water supplies without adequate treatment.

Two basic approaches can be taken to mitigate pollution of ground and surface waters by landfill leachates. The first, taken in most

cases, involves treatment of the leachate as it is produced by the landfill at a rate determined by site-specific infiltration and other conditions. The variation of leachate strength with time in fills that are not subject to moisture application indicates the period of production of high-strength leachate can be quite lengthy. If treatment is provided by passive attenuation techniques (e.g., passage through soil), this long time frame may not be important; the time frame will, however, be increasingly important as required treatment procedures become more complex, with concomitant increases in management and maintenance responsibilities and costs.

The important difference between a very old landfill that has substantially degraded its waste to the maximum extent possible by biological mechanisms and a young fill still undergoing active decomposition is not the quantity of leachate produced per unit time, but the quality of the leachate produced. If it is assumed for purposes of comparison that leachate from a biologically stabilized fill requires no further treatment prior to discharge, then it can be seen that the more rapidly a fill can be degraded, the shorter the time leachate treatment would be required. This introduces the second approach that can be taken in attenuating the leachate produced by a landfill, that of recirculation to accelerate biostabilization.

The effectiveness of leachate recirculation in mitigating leachate pollutional capacity will vary according to the leachate constituents of concern. The components examined by the current study can be divided into three categories, according to whether they might be expected to (1) degrade to innocuous end products or change toward levels found in unpolluted waters, (2) be relatively immobilized within the refuse mass by precipitation, adsorption, chelation, or other mechanisms, or (3) be unaffected and therefore available for continued leaching, irrespective of the extent of refuse decomposition or changes in the biological/physical-chemical conditions within the cell. This breakdown is presented in Table 11, together with predicted trends.

In general, mineral components in varying forms are conserved and unaffected by bacterial action, while organic compounds and chemical species such as sulfate (SO_4) are transformed to end products such as methane (CH_4), carbon dioxide (CO_2), water (H_2O), and hydrogen sulfide (H_2S). The mobility of a large number of metals is broadly affected on an inverse basis by leachate pH. Stabilization of the refuse usually results in elevation of the leachate pH, approaching neutrality, which tends to decrease the solubilization of many metallic ions, the transition elements zinc, cadmium, mercury and lead being the most highly influenced. The halogens, alkali metals, and alkaline earths largely remain available for leaching under a wide range of conditions. These last, therefore, may represent the most likely components to be leached from even a completely stabilized fill.

Table 12 compares Cell D leachate quality for certain parameters as observed at project commencement with the lowest stable concentrations achieved in that cell's leachate. Also shown are typical ranges of various parameters as typically encountered in municipal waste water.[10] Table 12 demonstrates that recirculation is effective to varying degrees

in attenuating the strength of leachate constituents. It is a highly effective method for achieving decreased organic loading as evidenced by the 98 to 99 percent removal of BOD, COD, and VA. BOD and COD of stabilized leachate are approximately equivalent to moderate strength municipal waste water. Recirculation was also reasonably effective in reducing the total dissolved solids (80+ percent) and the total Kjeldahl nitrogen content (70+ percent), although both are still approximately an order of magnitude above that of municipal waste water. The ionic strength of the leachate was decreased but still probably exceeds that of waste water by an order of magnitude (see chloride and TDS). Mao and Pohland[15] found that artificial control of leachate pH at near neutral values resulted in further acceleration of the stabilization beyond that provided by recycle alone. These observations indicate that the leachate from a recirculated landfill is likely to be significantly decreased in strength relative to an unrecirculated one (Cell A) but still, in most cases other than organic loading, to be stronger than municipal waste water. Additional treatment efforts may need to be taken, then, to further attenuate the leachate from a recycled fill before it is discharged.

Studies by Boyle and Ham,[11] Ho *et al.*,[12] Cook and Foree,[13] Thornton and Blanc,[14] and others indicate that, as regards leachate treatment, other methods may be as effective as recirculation or may be suitable adjuncts for furthering the treatment. Boyle and Ham examined both aerobic and anaerobic treatment of leachate (10,000 mg/l COD) and concluded that anaerobic methods were the most promising, yielding a BOD reduction exceeding 90 percent at a 10-day retention time and temperature between 23-30° C. Anaerobic processes deteriorated markedly under conditions of reduced temperature (ca. 10° C), an important consideration if non-heated processes are considered in cold climates. Aerobic polishing of the effluent leachate resulted in achievement of BOD values commensurate with surface discharge (BOD = 40+ mg/l). Cook and Foree utilized aerobic treatment and found leachate BOD (7000+ mg/l) to be attenuated to 30 mg/l in 10 days. Effluent polishing by treatment with activated carbon further reduced residual COD, organics, and color. Sodium hypochlorite (bleach) was effective in color removal, but had little effect on COD. Other physical-chemical treatments (alum, lime, $FeCl_3$) were effective in total suspended solids removal and moderately effective in color removal, but relatively ineffective in COD removal. Work by Ho *et al.* on the chemical treatment of leachates found lime addition to be effective in removing multivalent cations (iron in particular) and color. None of the treatments tested appeared likely to have any significant effect on COD or Cl^- concentrations. Boyle and Ham investigated the effect of addition of high-strength leachate in varying proportions to domestic waste water on the operation of the extended aeration treatment process utilized by many municipalities for waste water treatment. Results indicate that this treatment process should be able to handle leachate with COD of approximately 10,000 mg/l at loadings up to 5 percent by volume without seriously impairing effluent quality. Higher concentrations were found to degrade treatment process operation due to increased loading of total solids, unfiltered BOD, and COD.

Results of this and other studies, therefore, indicate landfill recirculation to be as effective in improving leachate quality as externally operated aerobic or anaerobic methods. Recirculation is less

likely to be affected by cold weather and thus may be a superior method under those conditions. Additional chemical treatment of effluents for either recirculation or external biodegradation can further reduce the concentration of multivalent ions ($Fe^{+2,3}$, Ca^{+2}, Mg^{+2}, etc.) and improve color. None of the chemical or physical processes attempted to date have been effective in reducing the total mineralization of the leachate to levels commensurate with those found in wastewater treatment plant discharge. Inorganic ions (Cl^-, $SO_4^=$, Na^+, K^+, etc.) would be expected to be attenuated by sorption mechanisms upon passage through appropriate clayey soils, or external treatments such as ion exchange or membrane filtration techniques might be employed.

Gas Production: Biodegradation of the susceptible organic constituents of the waste deposited within a landfill results in the production of various gases (methane, carbon dioxide, hydrogen, nitrogen, ammonia, and hydrogen sulfide) in amounts dependent upon the particular microbiologic processes occurring. From a theoretical standpoint, completed microbial degradation of one pound of typical municipal refuse under optimal conditions should yield approximately 3 cubic feet of CO_2 and 4 cubic feet of methane. Typically, a landfill will undergo an initial, relatively short phase of aerobic (oxygen-requiring) decomposition, followed by an extended period of anaerobic (oxygen-free) degradation. The methane-producing stage of anaerobic landfill biodegradation, which may last for many years, is the most significant from an operational standpoint, because of its duration and the potential impacts of its by-products.

Operationally, landfill gas production can have several effects worthy of consideration. Methane is combustible in concentrations of 5 to 15 percent by volume in air, and explosive if ignited in a confined space. Methane and other gases can migrate beyond fill limits, often to significant distances, given appropriate permeable boundary soil conditions and impeded cover venting. For these reasons, landfill design must incorporate provisions for protection of on-site buildings from methane accumulation and assure that off-site methane migration is controlled to eliminate hazard development in adjacent structures. An additional consideration is the fact that solution of carbon dioxide in water can increase the acid nature of the water, increasing the solubilization of many minerals and possibly resulting in increased water hardness or metallic content.

The rate of gas production is dependent on a complex set of factors, among the more important being moisture content and the amount of undegraded organic material remaining in a landfill, a property likely to be indicated by COD and VA content of the leachate produced. In situations where moisture content is not limiting, gases will continue to be produced throughout the period of biologic waste degradation. A stabilized fill--as indicated by low COD and VA--would be expected to produce gases at a low rate and thus to greatly minimize the potential for significant gas migration. Landfills with significant quantities of organic material remaining (high COD and VA) would be expected to produce gases at higher rates. Gas migratory control, if required, is most likely to be necessary during the period a fill is undergoing high rate decomposition (has high COD and VA). From Figures 3 and 16 this would be approximately 2 years for landfills with characteristics like those of Cell D, and

apparently a very long time for those resembling Cells A, B, and E. Recycle of leachate apparently would be very effective (pH adjustment for maximal effect) in minimizing the period of time a gas control system would need to be operated at a sanitary landfill.

Settlement: The rate of settlement generally follows the rate of biodegradation, perhaps as represented by the rate of change in organic loading as indicated by parameters such as COD, BOD, or VA. The more rapidly a landfill achieves biological stabilization, the more rapidly it will undergo that portion of total surface settlement attributable to densification of the refuse resulting from its biodegradation. It is estimated that settlement attributable to biologic transformation of the waste represents the major portion of the total settlement. Figure 18 graphically illustrates the effectiveness of recirculation in enhancing the rate of stabilization and therefore in shortening the time during which significant settlement occurs.

The ultimate extent to which a fill settles is largely dependent upon the degree of compaction of the waste that occurred upon placement, with the rate of settlement being dependent upon moisture content. The refuse placed in the test cells of this study achieved densities in excess of 350 kg/cubic meter (1000 lb/yd^3) which is comparable to that achieved in well operated sanitary landfills placing waste of similar moisture content (20 to 30 percent wet weight). The present settlement of Cell D (ca. 20 percent) may well be indicative of the ultimate settlement that might be achieved in full-size landfills with similar refuse characteristics. The response of control Cell A, however, indicates that, without special management such as continual addition of moisture, the time frame of achieving this settlement may be quite lengthy.

The significance of the extent of landfill settlement for construction toward a final planned end use is evident. Where final site topography is being created by refuse placement, allowance should be made by raising the final fill surface above the ultimate elevation desired by an amount commensurate with the projected settlement. The combination of long time frame and magnitude of ultimate settlement will restrict the uses to which a landfill can be placed or impose extensive considerations for design solution. These considerations are well summarized in Chapter 8 of Reference 3.

VII. IMPLEMENTATION OF RECIRCULATION AT FULL-SCALE LANDFILLS

Establishment of leachate recirculation at an existing landfill obviously requires that the fill have been constructed to contain and collect any leachate generated. Fills constructed to these specifications are likely to become increasingly prevalent in those regions of the country experiencing relatively high rainfall and vulnerable groundwater conditions. Where collection of leachate is possible, reinjection into completed portions of a fill could be accomplished by constructing a distribution field of trenches or vertical wells designed to inject leachate within the upper level of the refuse fill.

Experience has shown, however, that leachate injection systems can often overload the percolation capacity of the adjacent refuse, thus becoming ineffectual. It is therefore necessary to match the leachate acceptance capacity of the system to the liquid application rate. This could be done either by continuous application of leachate to the field at a low rate or by sequentially applying the leachate to separate portions of the field in turn at a high flow rate for a short period, followed by a long recovery period. In most cases, it probably is not practical to establish leachate reinjection over an entire landfill. If implemented, it is most likely that only a portion of a landfill would be developed for recirculation, the extensiveness of the system being dictated by the volume of leachate generated by the entire site.

The selection of the portions of a fill to be committed to recycle should integrate projected end use plans with the positive attributes of fill response to recycle, such as rapid achievement of physical stability through accelerated settlement and limitation of the period of high gas production. Likely candidate areas for leachate application might be the following:

1. Locations of anticipated structures with associated access roadways and utility corridors.

2. Areas adjacent to off-site structures that might be adversely affected by long-term gas migration. These affected areas would need to be protected from gas during the period of active degradation in the recycle area, but would most likely have fewer long-term problems after stabilization had been achieved and gas control terminated.

3. Areas adjacent to sanitary sewer lines for ease of disposal of recirculated leachate or treated recirculated leachate.

Designating a limited portion of a landfill for recirculation might also allow additional benefits to operators as regards the remainder of the landfill. One possibility is that the remaining fill might benefit from having a highly permeable cover which would allow entrance of precipitation and free exit of gases. The flow of precipitation into and through the refuse should greatly accelerate the stabilization of the remaining refuse in the landfill. The leachate generated could then

be collected at the base of the fill and distributed to the recirculation area for treatment with subsequent discharge. The gases evolved during refuse decomposition would be able to leave the fill through the permeable surface, thus minimizing lateral migration.

Discharge of treated leachate from the recirculation area at a rate approximating landfill production will require a progressive recirculation system. To maximize leachate residence time in the fill and thus achieve optimum leachate quality, leachate would be progressively collected and reinjected through a sequence of subareas within the recirculation area. After collection from the last subarea, the leachate would be further treated as required to make it suitable for discharge. For such a design to be implemented, the area to be utilized for recirculation must be designed for this function from the beginning, and probably would be one of the first landfill areas to be completed.

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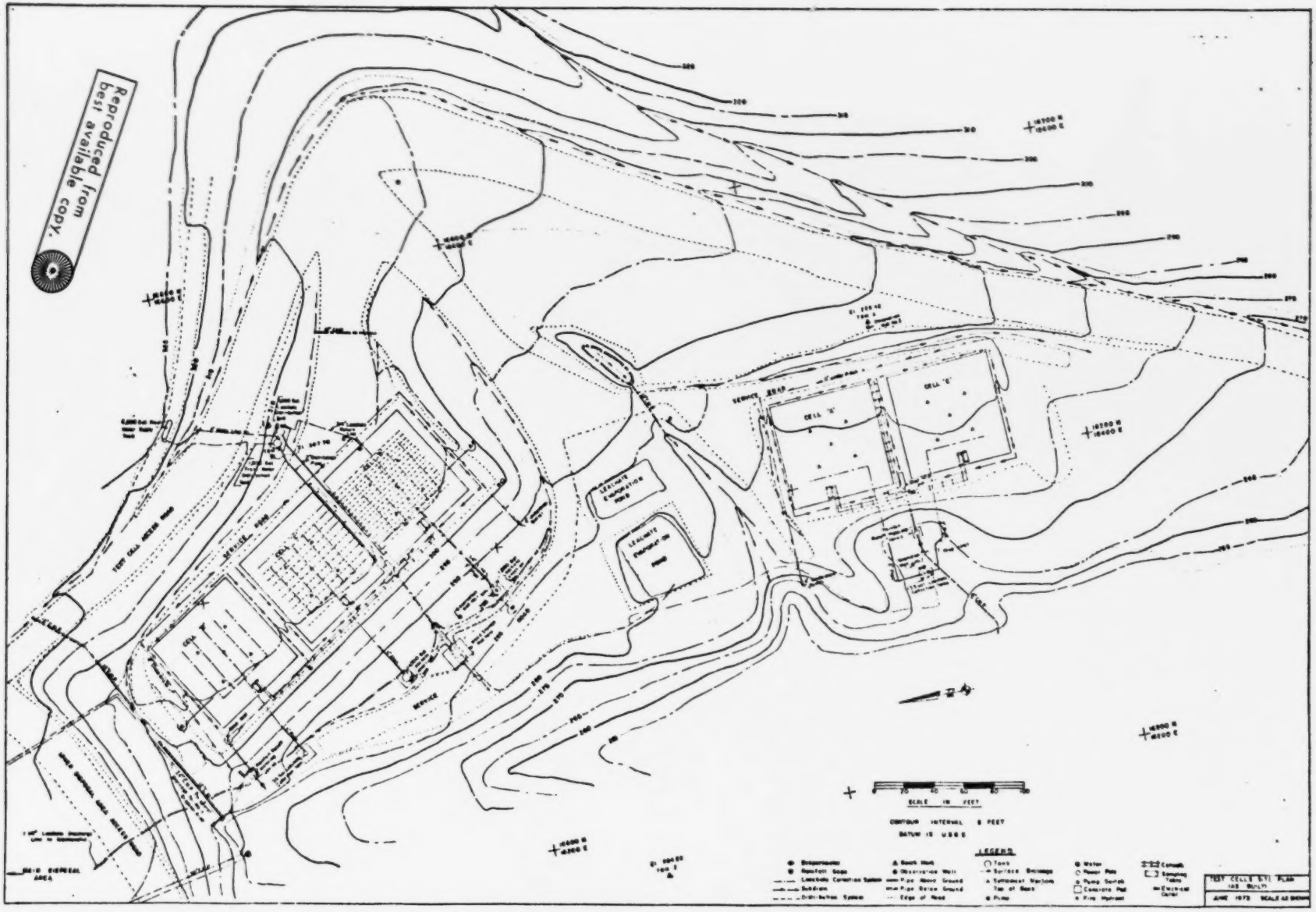
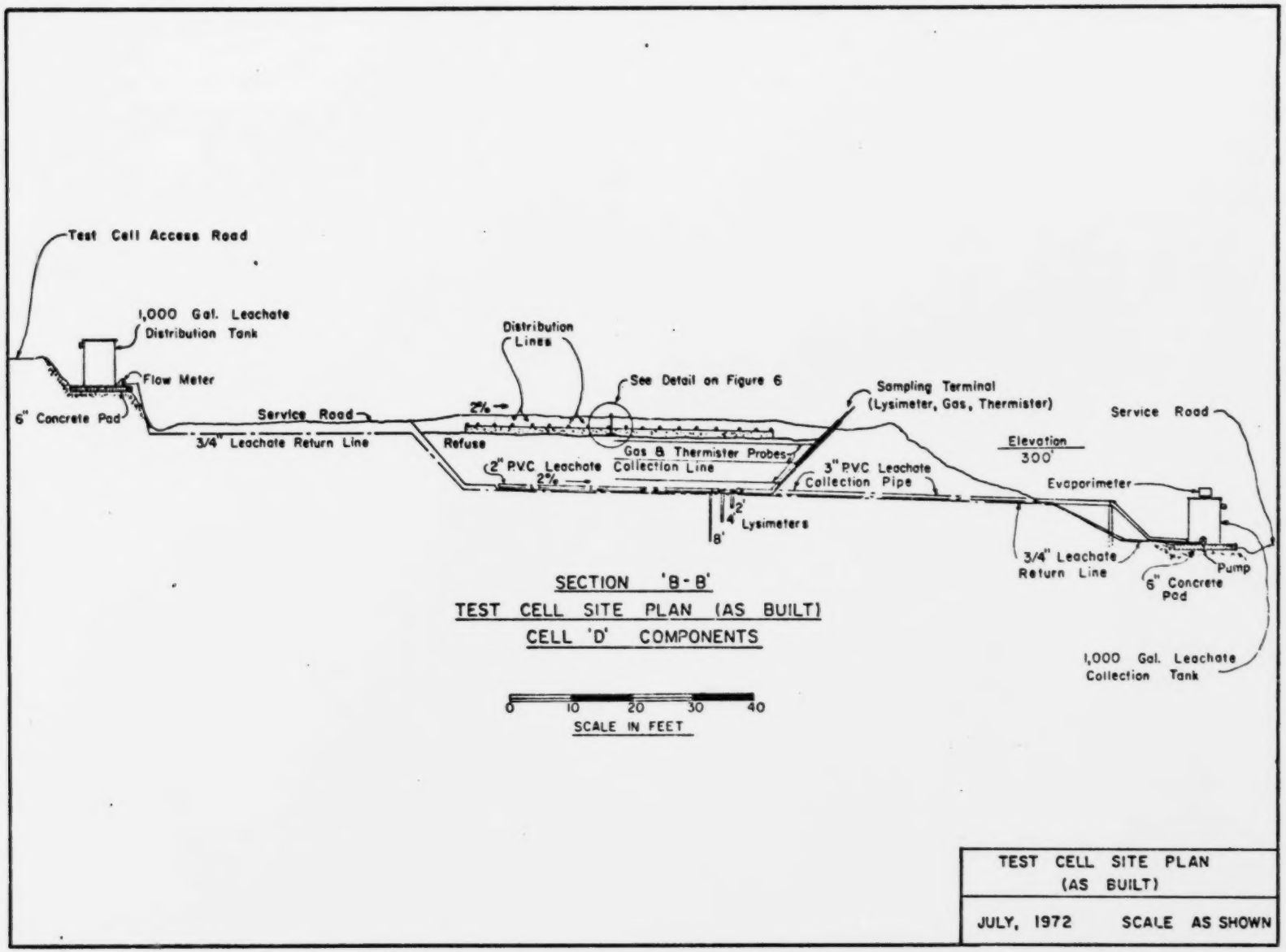


PLATE 1



SECTION 'B-B'

TEST CELL SITE PLAN (AS BUILT)

CELL 'D' COMPONENTS

TEST CELL SITE PLAN (AS BUILT)	
JULY, 1972	SCALE AS SHOWN

PLATE 2

TABLE 1

CONDITIONING, OPERATION AND PURPOSE OF TEST CELLS

CELL DESIGNATION	INITIAL		OPERATION		PURPOSE OF CELL
	LIQUID CONDITIONING	LIQUID USED	DAILY LIQUID APPLICATION gal/day	LIQUID USED	
A	None	None	None	None	Control Cell
B	Field Capacity*	Water	None	None	To determine the effect of high initial water content on refuse stabilization.
C	None	None	700± (200-1000)**	Water	To determine the effect of continuous water through flow on leachate character.
D	None	None	1000± (500-1000)**	Recirculated Leachate	To determine the effect of continuous leachate recirculation on leachate character.
E	Field Capacity*	Septic Tank Pumpings	None	None	To determine the effect of high initial moisture content, using septic tank pumpings, on refuse stabilization.

* Field capacity is the condition when a sufficient quantity of fluid has been added to the refuse to cause a significant volume of leachate to be produced from the cell.

** Range of variation in daily application of fluid.

TABLE 2

COMPOSITION OF REFUSE* - VARIOUS STUDIES

ITEM	SOURCE OF REFUSE		
	Sonoma Test Cells - Calif. (mean)[1]	National Center for Resource Recovery[14]	Fungaroli[8]
Food Waste	10.7	14.6	8.4
Garden Waste	10.4	12.5	6.9
Paper	40.6	42.7	53.3
Plastic, Rubber	4.6	3.5	1.6
Textiles	1.7	2.4	0.8
Wood	1.0	2.5	2.3
Metals	9.0	9.2	6.9
Glass, Ceramics	10.9	10.3	7.7
Ash, Dirt, Rock, etc.	2.8	2.3	2.3
Fines	8.3		9.8

* Percent wet weight.

TABLE 3

PARAMETERS MEASURED DURING STUDY

LEACHATE

Six Week

Alkalinity
Biochemical Oxygen Demand (BOD)
Chemical Oxygen Demand (COD)
Chloride (Cl^-)
Iron, Total (Fe)
Nitrogen, Total Kjeldahl (TKN)
Nitrogen, Nitrate (NO_3)
pH
Specific Conductance
Temperature
Volatile Acids (VA)

Twelve Week

Alkalinity
BOD
COD
Cl
Fe
Fecal Streptococci
Fecal Coliform
Lead (Pb)
Mercury (Hg)
N-TKN
N-NO_3
pH
Specific Conductance
Sulfate (SO_4)
Temperature
Total Dissolved Solids (TDS)
VA
Zinc (Zn)

GAS (semiannually)

% by volume
Methane (CH_4)
Carbon Dioxide (CO_2)
Nitrogen (N_2)
Oxygen (O_2)

SETTLEMENT (three times)

% settlement

OTHER (semiannually)
(Groundwater Wells
Water Added - Cell C
Cells A & E Subdrain)

Dissolved Oxygen (DO)
pH
Temperature
EC
Water Level (where appropriate)

TABLE 4

LEACHATE ANALYSIS - Cell A

COMPONENT(1)	SAMPLE COLLECTION DATE									
	2/19/75	4/9/75	5/22/75	6/27/75	8/14/75	9/30/75	11/20/75	12/30/75	2/3/76	
Alkalinity	2,316	5,886	7,722	9,405	15,939	15,840	8,910	11,088	14,949	
B.O.D.	12,100	30,650	33,350	42,150	42,850	44,700	23,000	42,000	38,600	
C.O.D.	43,608	49,828	59,994	69,172	71,315	59,123	33,368	44,770	27,550	
Chloride	650	1,320	2,299	2,449	3,017	1,531	2,970	2,258	4,148	
Fecal Coli. MPN/100 ml	15	-	-	3	-	-	3	-	3	
Fecal Strep. MPN/100 ml	2,100	-	-	9.3	-	-	< 3	-	11,000	
Iron	410	690	1,015	740	1,537	1,350	880	1,303	1,282	
Lead	0.28	-	0.61	-	0.7	-	0.32	-	0.63	
Mercury	0.338	-	0.036	-	0.005	-	0.074	-	0.033	
Nitrogen - Kjeldahl	581	931	1,008	1,309	1,182	1,061	601	853	989	
Nitrogen - Nitrate	0.234	0.23	<0.008	1.0	1.42	0.42	0.2	0.9	<0.04	
pH(2)	5.2	6.2	4.6	5.5	5.5	5.2	5.1	5.7	5.7	
Solids - T.D.S.	14,970	-	33,340	-	20,400	-	21,324	-	34,364	
Specific Cond.(2) μ mhos/cm	10,000	16,000	21,000	13,000	18,000	18,000	22,000	15,000	17,500	
Sulfate	622	-	1,146	-	1,160	-	606	-	1,075	
Temperature (2) (°C)	12.0	15.0	16.0	26.0	19.0	14.0	-	15.0	15.0	
Volatile Acids	9,300	11,238	22,920	26,640	27,360	22,800	15,540	20,520	26,460	
Zinc	52	-	97	-	116	-	46	-	101	

(1) Units in mg/l unless otherwise noted.

(2) Measured at time of sample collection.

TABLE 5

LEACHATE ANALYSIS - Cell B

COMPONENT(1)	SAMPLE COLLECTION DATE									
	2/19/75	4/9/75	5/22/75	6/27/75	8/14/75	9/30/75	11/20/75	12/30/75	2/3/76	
Alkalinity	3,860	5,114	5,544	6,237	9,702	9,603	9,207	10,197	No Leachate Produced	
B.O.D.	18,000	41,750	21,250	35,300	34,150	31,750	27,000	30,260		
C.O.D.	53,728	71,953	46,879	45,724	46,479	58,726	41,516	44,880		
Chloride	1,250	1,565	2,788	2,849	2,404	1,723	4,008	2,642		
Fecal Coli. MPN/100 ml	9	-	-	<3	-	-	< 3	-		
Fecal Strep. MPN/100 ml	2,100	-	-	43	-	-	< 3	-		
Iron	452	930	580	345	733	626	505	303		
Lead	0.40	-	0.39	-	0.4	-	0.43	-		
Mercury	0.276	-	0.008	-	0.006	-	0.036	-		
Nitrogen - Kjeldahl	1,073	1,146	1,108	1,210	1,131	1,027	989	1,188		
Nitrogen - Nitrate	0	0.16	<0.008	0.1	<0.02	0.05	<0.01	0.5		
pH(2)	5.5	5.4	4.6	5.5	5.5	5.6	5.0	5.7		
Solids - T.D.S.	20,810	-	21,600	-	22,100	-	20,580	-		
Specific Cond.(2) μ mhos/cm	14,000	16,000	16,000	12,800	14,000	14,000	15,000	15,000		
Sulfate	802	-	720	-	805	-	719	-		
Temperature (2) (°C)	14.0	13.0	13.0	28.0	15.0	14.0	-	15.0		
Volatile Acids	11,940	12,138	15,600	16,200	17,100	17,640	16,560	15,480		
Zinc	46	-	60	-	42	-	42	-		

(1) Units in mg/l unless otherwise noted.

(2) Measured at time of sample collection.

TABLE 6

LEACHATE ANALYSIS - Cell C

COMPONENT (1)	SAMPLE COLLECTION DATE									
	2/19/75	4/9/75	5/22/75	6/27/75	8/14/75	9/30/75	11/20/75	12/30/75	2/3/76	
Alkalinity	772	1,061	1,188	1,584	1,287	1,386	1,584	1,287	1,188	
B.O.D.	2,725	4,900	2,900	3,050	2,400	1,710	1,450	1,680	1,430	
C.O.D.	9,641	3,775	4,412	3,752	2,874	2,182	2,483	3,108	2,688	
Chloride	100	7,592	114	121	546	60	514	496	849	
Fecal Coli. MPN/100 ml	15	-	-	290	-	-	61	-	35	
Fecal Strep. MPN/100 ml	2,400	-	-	290	-	-	< 3	-	24,000	
Iron	292	325	310	325	486	-	316	225	233	
Lead	0.12	-	0.17	-	0.03	-	0.04	-	0.15	
Mercury	0.312	-	0.542	-	0.007	-	0.093	-	0.033	
Nitrogen - Kjeldahl	146	130	130	120	72	66	78	103	77	
Nitrogen - Nitrate	<0.01	0.06	0.08	0.5	<0.02	0.3	0.04	1.2	1.0	
pH (2)	5.6	6.5	6.4	6.3	6.3	6.7	6.0	6.4	6.1	
Solids - T.D.S.	3,640	-	2,884	-	2,268	-	2,328	-	1,828	
Specific Cond. (2) μ mhos/cm	3,100	5,500	3,000	2,300	1,950	2,500	2,200	2,000	2,250	
Sulfate	73	-	38	-	75	-	38	-	27	
Temperature (2) (°C)	14.0	16.5	17.0	25.5	18.5	18.0	-	15.0	15.0	
Volatile Acids	2,640	1,735	1,920	1,368	1,200	984	720	1,392	864	
Zinc	1.79	-	24	-	51	-	12	-	0.5	

(1) Units in mg/l unless otherwise noted.

(2) Measured at time of sample collection.

TABLE 7

LEACHATE ANALYSIS - Cell D

COMPONENT (1)	SAMPLE COLLECTION DATE									
	2/19/75	4/9/75	5/22/75	6/27/75	8/14/75	9/30/75	11/20/75	12/30/75	2/3/76	
Alkalinity	2,316	2,798	2,574	2,475	2,574	2,871	2,772	2,772	2,871	
B.O.D.	202	190	123	385	152	111	104	145	143	
C.O.D.	1,899	394	539	625	525	460	512	429	685	
Chloride	2,000	244	506	514	539	305	555	536	770	
Fecal Coli. MPN/100 ml	930	-	-	120	-	-	20	-	43	
Fecal Strep. MPN/100 ml	24,000	-	-	1,200	-	-	23	-	24,000	
Iron	72	110	100	47	100	55	51	50	50	
Lead	0.16	-	0.10	-	0.06	-	0.22	-	0.12	
Mercury	1.236	-	0.006	-	0.011	-	0.020	-	0.028	
Nitrogen - Kjeldahl	214	210	217	219	246	212	205	229	256	
Nitrogen - Nitrate	<0.01	0.4	0.02	0.4	0.5	0.63	0.02	0.14	1.2	
pH (2)	6.6	6.3	6.2	6.6	6.8	6.9	6.2	7.0	6.7	
Solids - T.D.S.	3,350	-	3,216	-	3,252	-	3,264	-	3,244	
Specific Cond. (2) μ mhos/cm	4,700	12,000	6,000	5,500	4,900	5,000	8,000	6,000	6,000	
Sulfate	240	-	16.5	-	69	-	82	-	27	
Temperature (2) (°C)	13.0	15.5	16.0	24.0	19.5	19.0	-	16.5	16.0	
Volatile Acids	120	36	312	96	86	96	24	216	168	
Zinc	0.34	-	0.17	-	0.13	-	0.93	-	1.0	

(1) Units in mg/l unless otherwise noted.

(2) Measured at time of sample collection.

TABLE 8

LEACHATE ANALYSIS - Cell E

COMPONENT(1)	SAMPLE COLLECTION DATE									
	2/19/75	4/9/75	5/22/75	6/27/75	8/14/75	9/30/75	11/20/75	12/30/75	2/3/76	
Alkalinity	6,080	5,983	5,742	7,326	11,385	11,583	10,890	10,890	11,583	
B.O.D.	23,000	38,250	19,000	30,150	38,100	33,700	32,700	28,000	37,750	
C.O.D.	86,480	36,120	50,249	50,648	52,156	44,838	53,156	45,510	40,992	
Chloride	1,600	2,006	2,690	4,648	3,253	1,960	3,961	1,[illegible]9	3,998	
Fecal Coli. MPN/100 ml	<3	-	-	<3	-	-	< 3	-	< 3	
Fecal Strep. MPN/100 ml	750	-	-	<3	-	-	< 3	-	1,100	
Iron	692	690	770	514	1,083	-	840	865	1,000	
Lead	0.66	-	0.52	-	0.60	-	0.41	-	0.70	
Mercury	1.134	-	0.011	-	0.004	-	0.069	-	0.043	
Nitrogen - Kjeldahl	1,432	1,207	923	1,235	1,182	1,106	1,064	1,194	1,111	
Nitrogen - Nitrate	0.403	0.26	0.3	0.3	0.12	<0.03	<0.01	1.6	0.6	
pH(2)	5.3	5.4	4.6	5.6	5.4	5.4	5.0	5.6	5.7	
Solids - T.D.S.	29,070	-	25,688	-	27,532	-	27,012	-	25,652	
Specific Cond.(2) μ mhos/cm	17,000	18,000	17,500	12,000	16,000	16,500	19,000	16,000	16,800	
Sulfate	1,271	-	849	-	1,093	-	460	-	759	
Temperature (2) (°C)	10.0	15.0	16.0	29.0	17.5	14.0	-	15.0	15.0	
Volatile Acids	18,600	12,378	18,360	18,480	20,160	12,900	19,620	16,992	18,300	
Zinc	74	-	74	-	91	-	69	-	64	

(1) Units in mg/l unless otherwise noted.

(2) Measured at time of sample collection.

TABLE 9

TEST CELL GAS COMPOSITION DATA

Sample Source Gas Component	2/19/75 Uncorrected	2/19/75 Corrected*	11/20/75 Uncorrected	11/20/75 Corrected*
Cell A				
CH_4	0.6	1.1	1.2	1.3
CO_2	28.2	50.3	76.9	80.8
N_2	66.6	48.6	21.1	17.9
O_2	4.5	0.0	0.8	0.0
Cell B				
CH_4	2.5	3.0	13.3	18.1
CO_2	41.1	50.1	37.5	51.2
N_2	54.5	46.9	45.5	30.7
O_2	1.9	0.0	3.7	0.0
Cell C				
CH_4	61.7	70.7	70.2	70.2
CO_2	24.3	27.9	29.6	29.6
N_2	11.4	1.4	0.2	0.2
O_2	2.5	0.0	0.0	0.0
Cell D				
CH_4	55.8	61.5	66.8	66.8
CO_2	35.0	38.5	30.3	30.3
N_2	7.0	0.0	2.9	2.9
O_2	2.2	0.0	0.0	0.0
Cell E				
CH_4	7.0	32.7	20.5	20.5
CO_2	14.4	67.3	68.0	68.0
N_2	57.1	0.0	11.5	11.5
O_2	21.5	0.0	0.0	0.0

* See text for explanation

TABLE 10

GROUNDWATER AND WATER ADDED, CELL C
QUALITY MONITORING DATA

Source	Date	pH	Spec. Cond. (μhos/cm)	Dissol.[a] Oxygen (mg/l)	Temp. (°C)	Depth to Water (m)
Well 1	Initial[c]	7.3	480	5.5	18.0	1.7
	4/9/75	7.2	400	7.4	14.0	0.5
	9/30/75	7.2	450	1.2[b]	19.0	1.5
Well 2	Initial[c]	7.2	370	5.7	18.0	2.3
	4/9/75	7.2	130	10.0	14.0	0.7
	9/30/75	6.8	1200	2.8[b]	20.0	1.9
Well 3	Initial[c]	7.2	320	6.0	18.0	2.2
	4/9/75	7.3	65	6.8	14.0	1.2
	9/30/75	7.4	300	2.7[b]	19.0	1.6
Well 4	Initial[c]	6.7	310	4.9	18.0	2.2
	4/9/75	6.8	75	7.8	16.0	4.1
	9/30/75	7.8	470	3.4[b]	19.0	5.5
Water Added Cell C	Initial[c]	7.8	800	8.0	18.5	-
	4/9/75	8.2	60	10.2	13.5	-
	9/30/75	7.4	280	6.6[b]	15.0	-
Cells A&E Subdrain	Initial[c]	5.8	400	5.5	18.0	-
	4/9/75	7.5	220	7.0	16.0	-
	9/30/75	No flow	-	-	-	-

a. Method of sampling results in extensive sample aeration and would serve to invalidate D.O. measurements.

b. Questionable data - probable instrument malfunction.

c. Mean of 1972 data.

TABLE 11

ANTICIPATED FATE OF LEACHATE COMPONENTS

A. Components that will degrade or properties that will change

Parameter	Predicted Trend
Alkalinity	Decrease
Biochemical Oxygen Demand (BOD)	Decrease - organics to CO_2, CH_4
Chemical Oxygen Demand (COD)	Decrease - organics to CO_2, CH_4
N-Nitrate (NO_3)	Decrease - nitrogenous compounds to NH_3
N-Total Kjeldahl (TKN)	Decrease - nitrogenous compounds to NH_3
pH	Increase toward neutrality
Total Dissolved Solids (TDS)	Decrease
Specific Conductivity	Decrease
Sulfate (SO_4)	Decrease - ultimately to H_2S
Volatile Acids (VA)	Decrease - organics to CO_2, CH_4

B. Immobilized compounds

Iron (Fe)	Decrease (function of pH increase)
Lead (Pb)	Decrease "
Zinc (Zn)	Decrease "

C. Compounds with enhanced or unaffected mobility

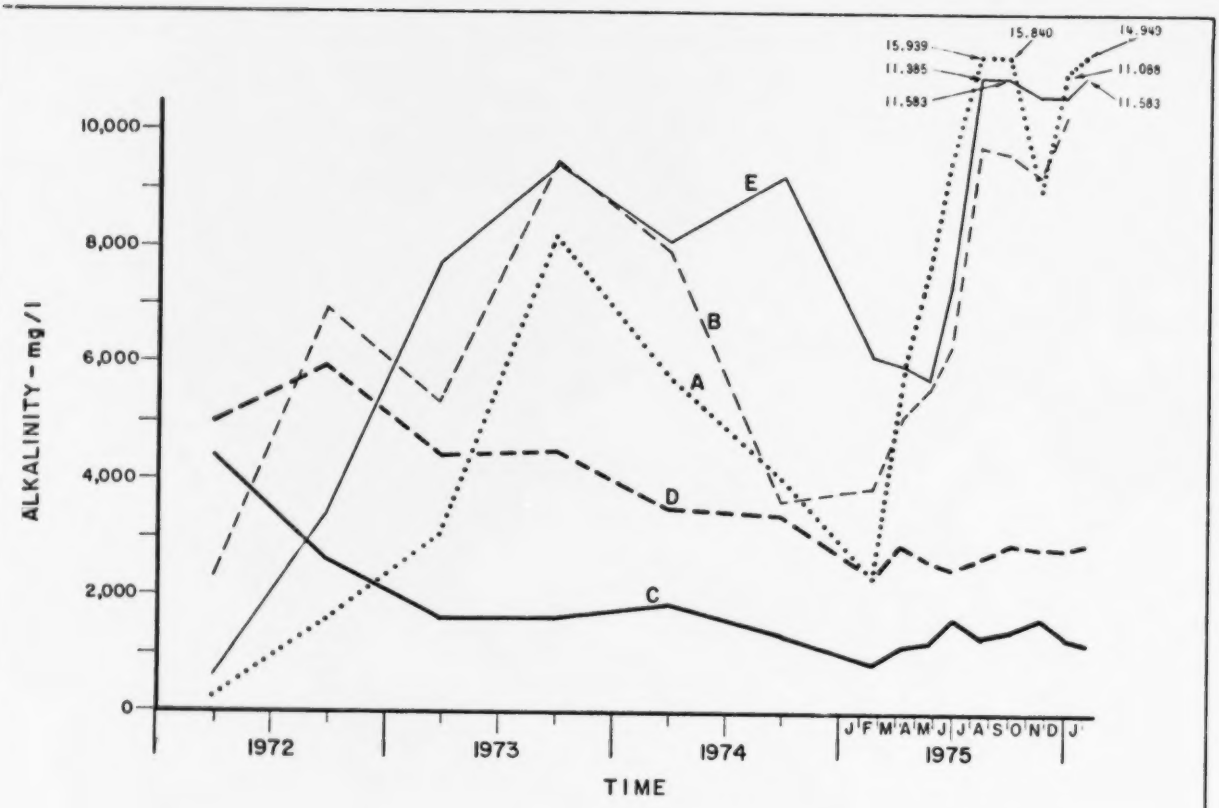
Chloride (Cl)	Little change

TABLE 12

CELL D LEACHATE
ATTENUATION AND RELATIONSHIP TO OTHER WASTE WATER

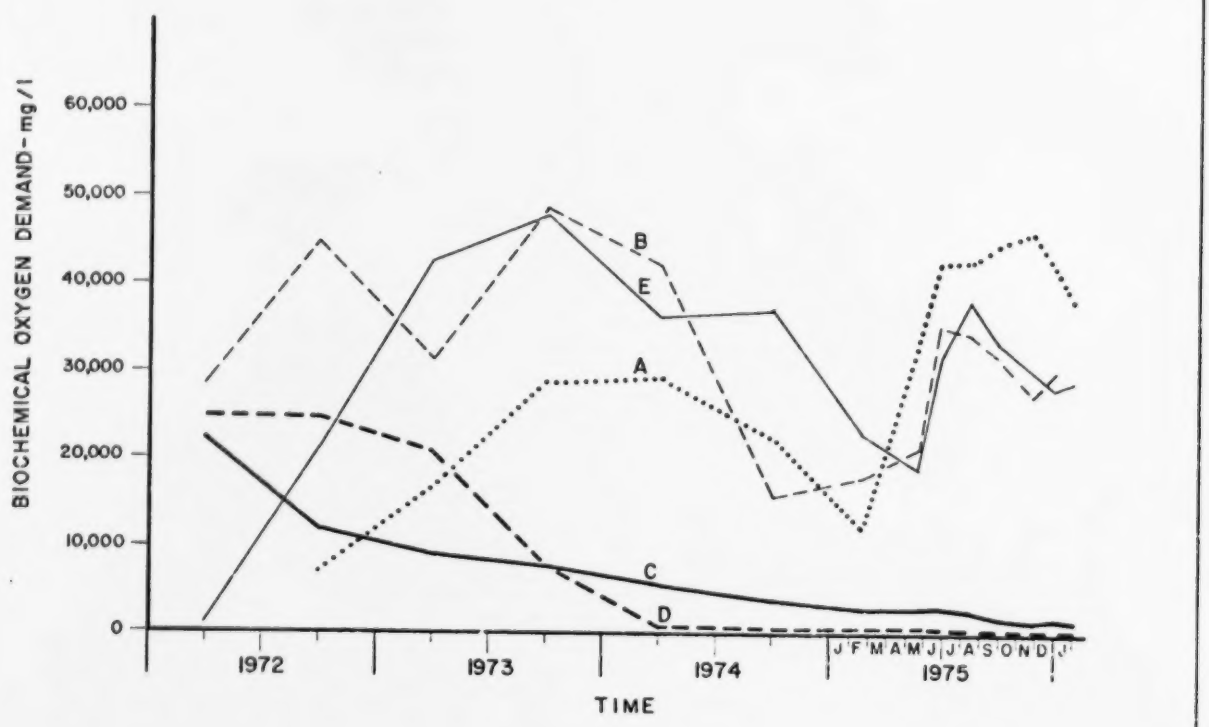
Parameter	CELL D			Cell A*	Domestic*[9]
	Initial* Leachate	Current* Leachate	% Change	Current Leachate	Waste Water
Alkalinity	5,000	2,500	50	12,000	50-200
BOD	25,000	150	99+	40,000	100-300
COD	37,000	500	98+	50,000	250-1000
Cl^-	1,000	500	50	2,500	30-100
Fecal Coli. MPN/100 ml	0	100	--	<3	--
Fecal Strep. MPN/100 ml	3.7×10^{-6}	500	99+	<3	--
Fe, Total	180	75	50+	1,000	--
Nitrogen, Total Kjeldahl	800	220	70+	1,000	20-85
pH	5.0	6.5	--	5.2	--
TDS	16,500	3,200	80+	20,000	250-850
Specific Cond. μ mhos/cm	11,000	6,000	40+	20,000	--
Volatile Acids	10,000	100	99	20,000	--
Zn	50	<1	98+	75	--

* Units in mg/l unless otherwise noted.



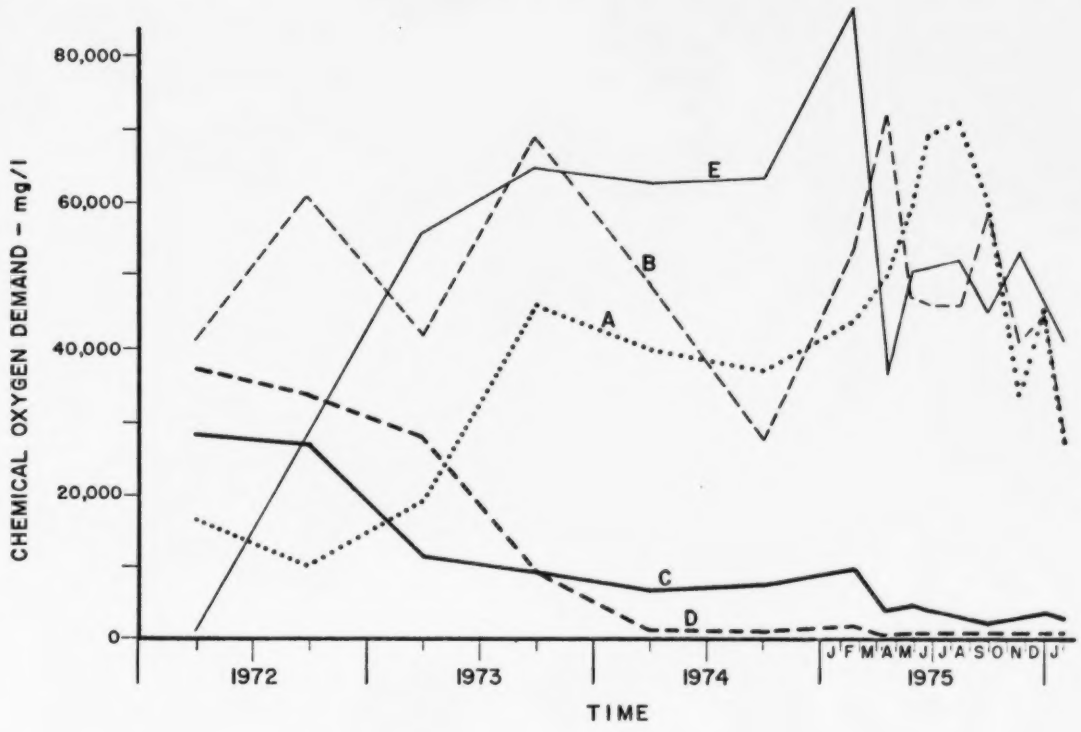
ALKALINITY OF LEACHATE

FIGURE 1



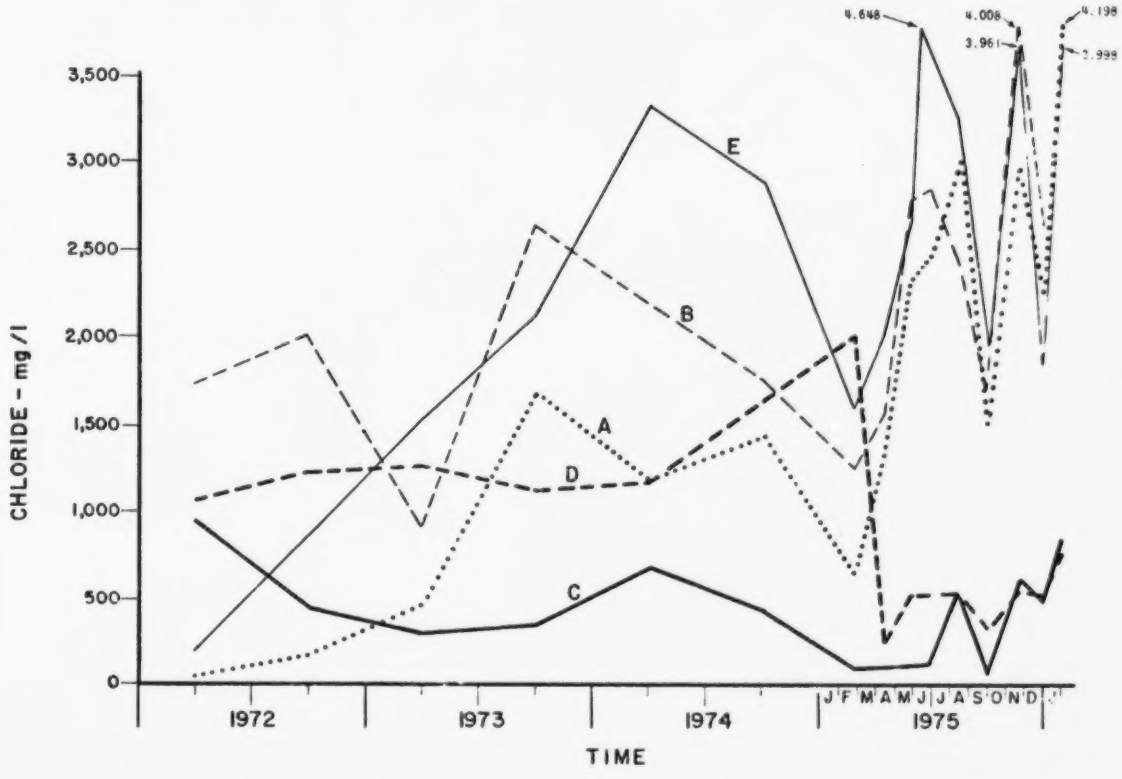
BIOCHEMICAL OXYGEN DEMAND OF LEACHATE

FIGURE 2



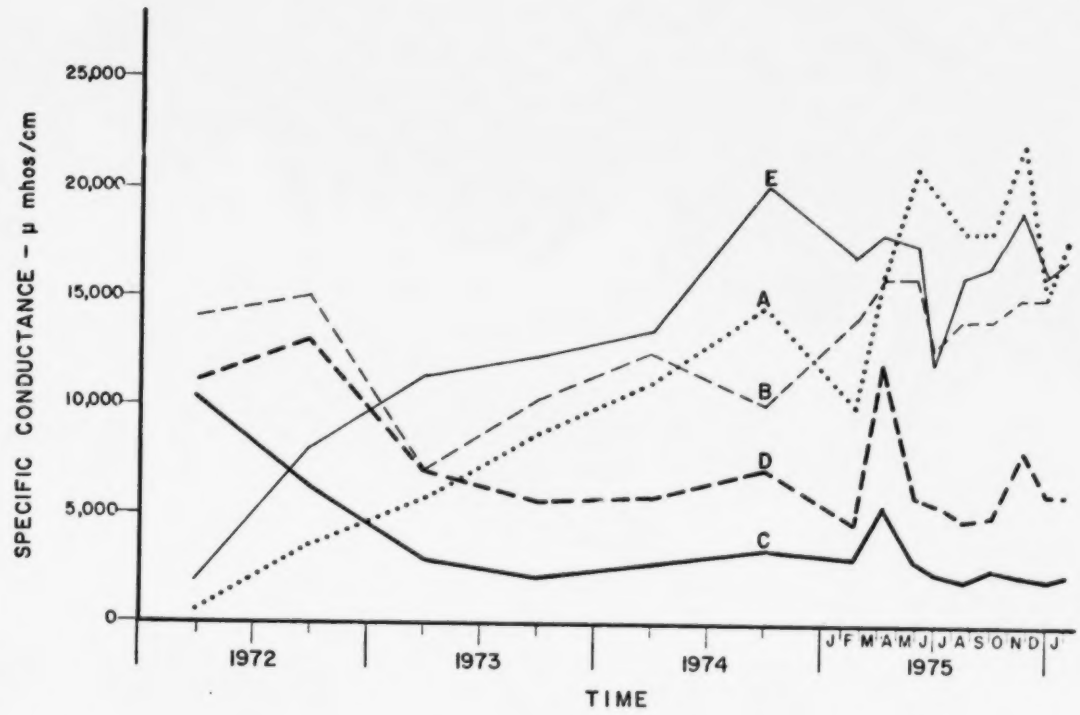
CHEMICAL OXYGEN DEMAND OF LEACHATE

FIGURE 3

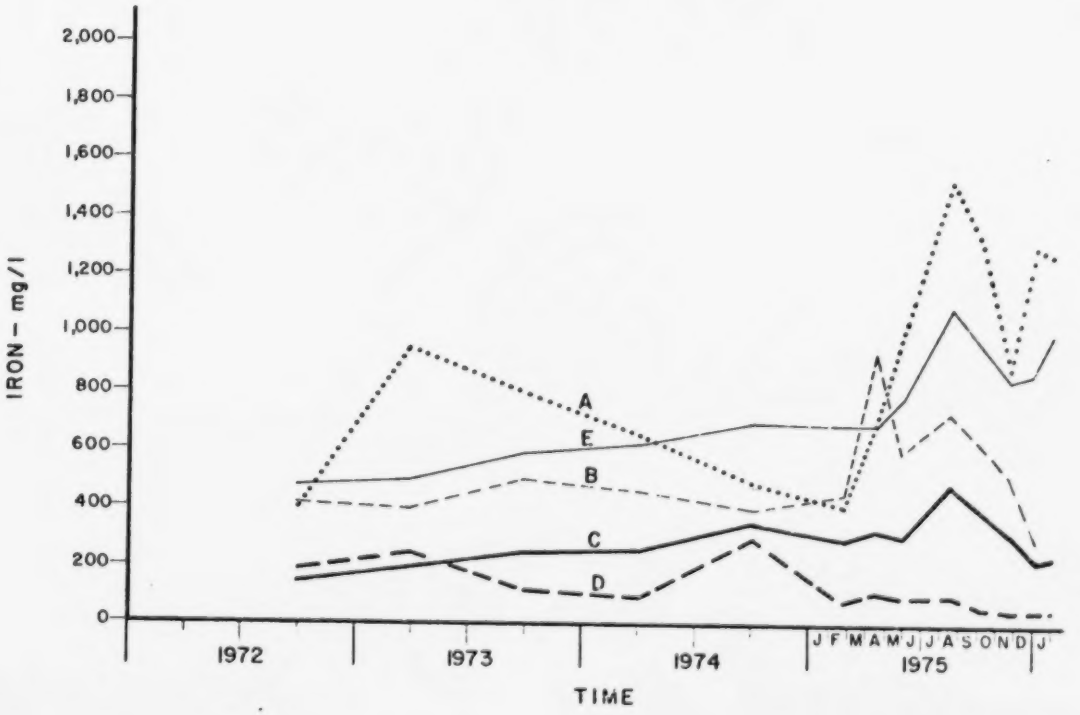


CHLORIDE CONCENTRATION OF LEACHATE

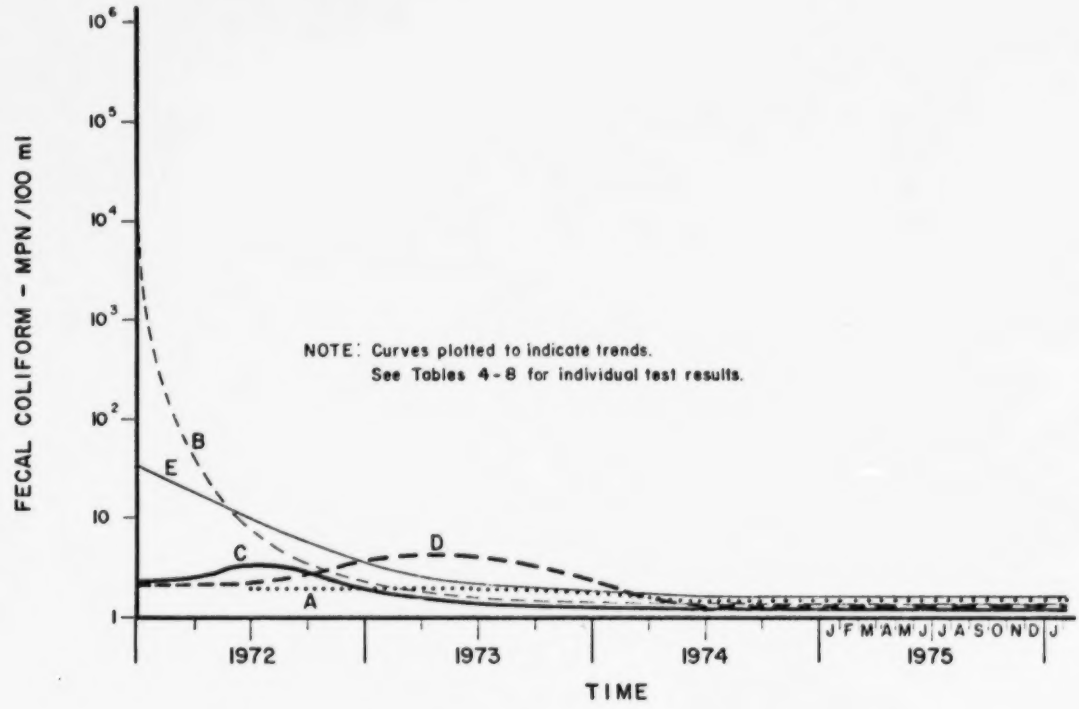
FIGURE 4



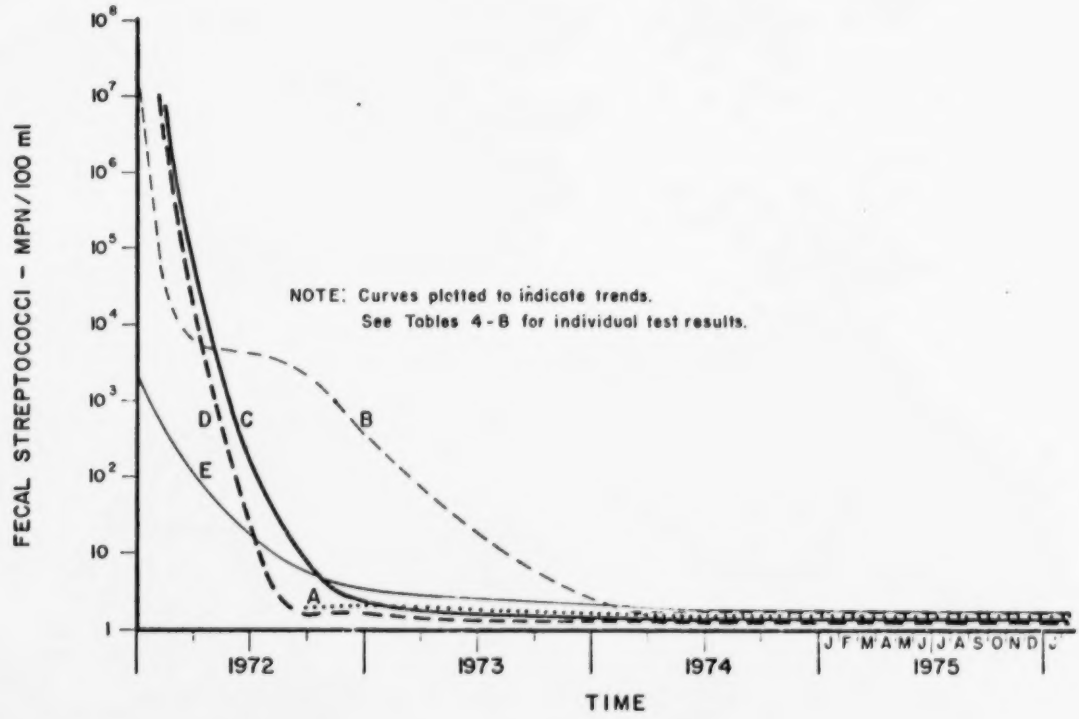
SPECIFIC CONDUCTANCE OF LEACHATE | FIGURE 5



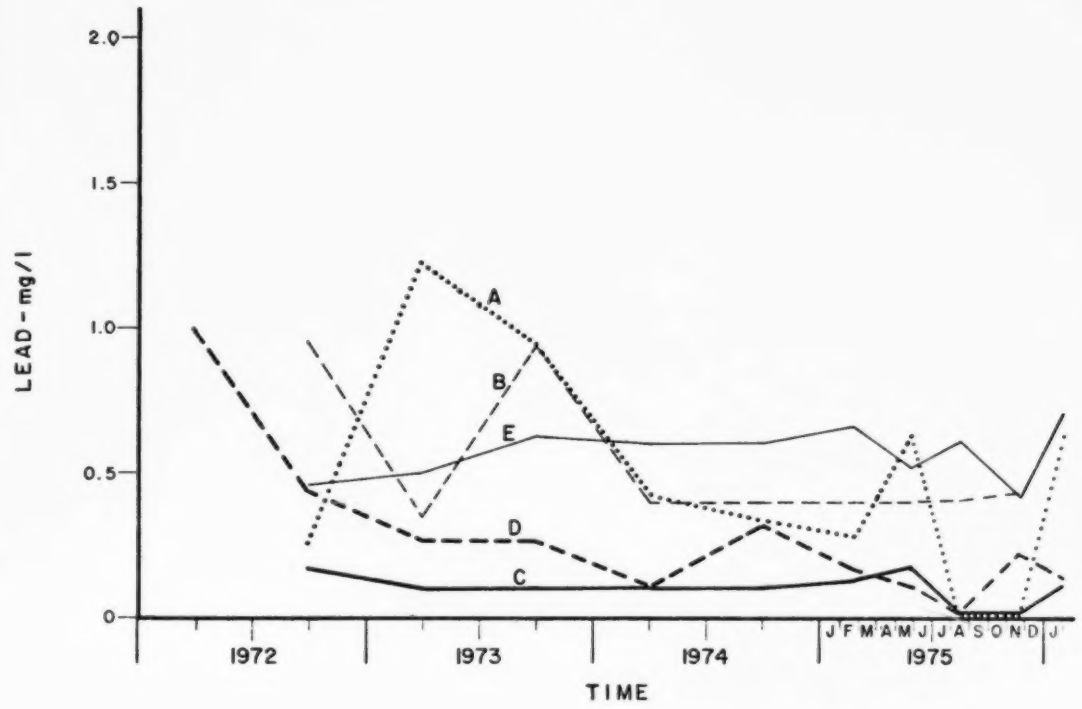
IRON CONCENTRATION OF LEACHATE | FIGURE 6



FECAL COLIFORM COUNT IN LEACHATE | FIGURE 7

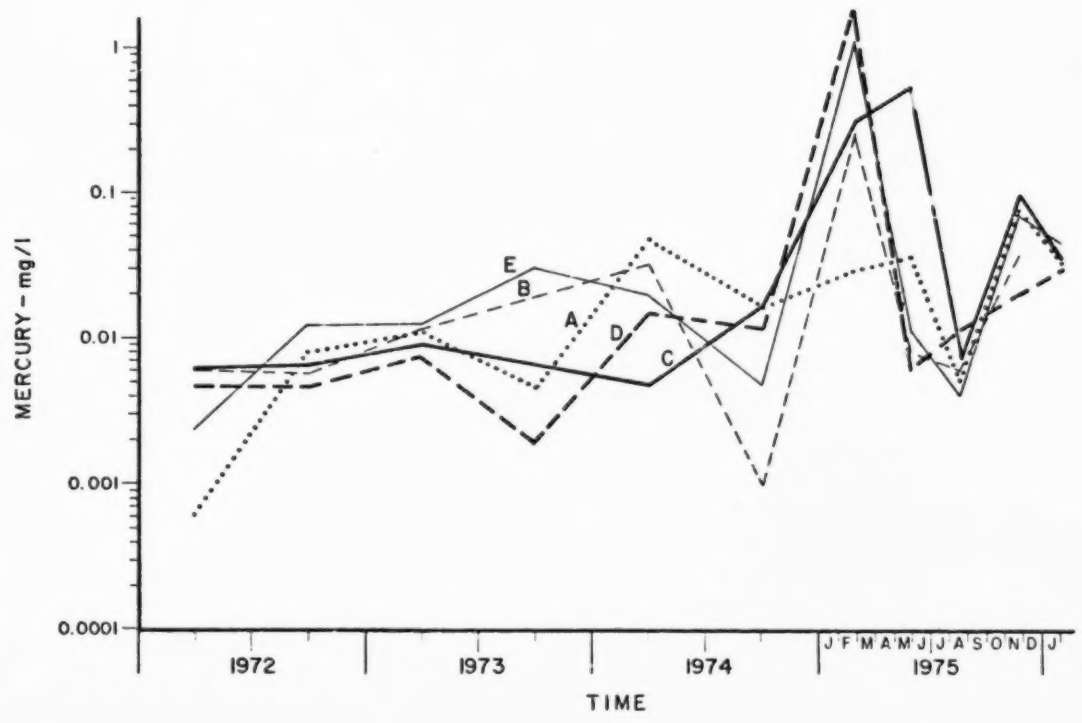


FECAL STREPTOCOCCI COUNT IN LEACHATE | FIGURE 8



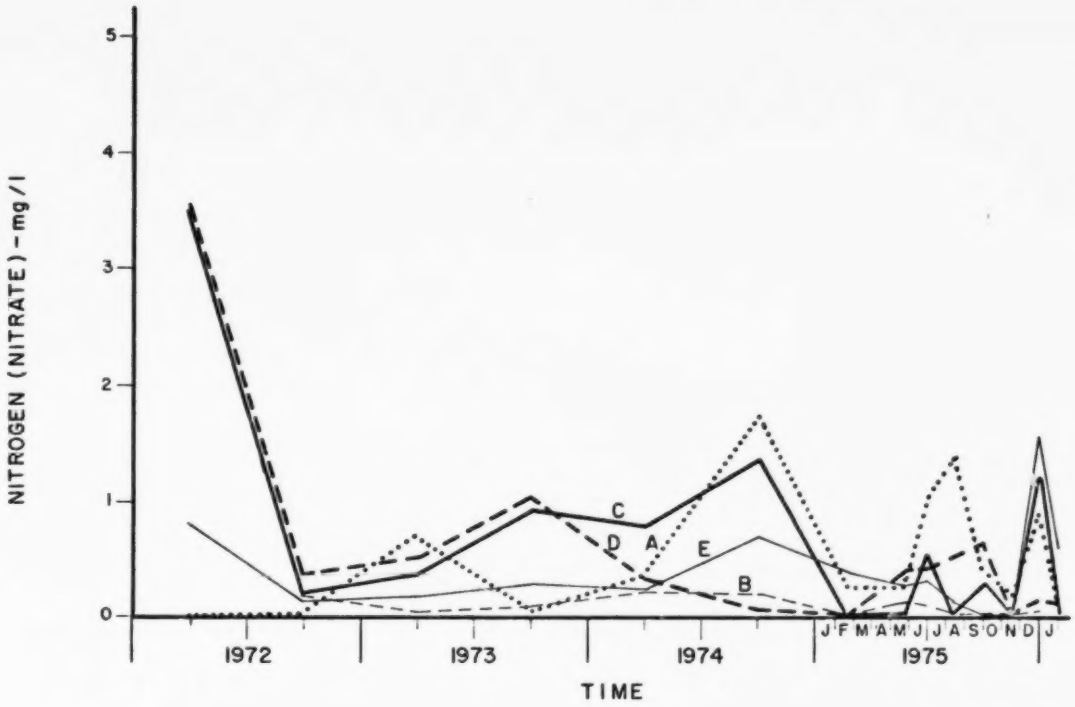
LEAD CONCENTRATION OF LEACHATE

FIGURE 9

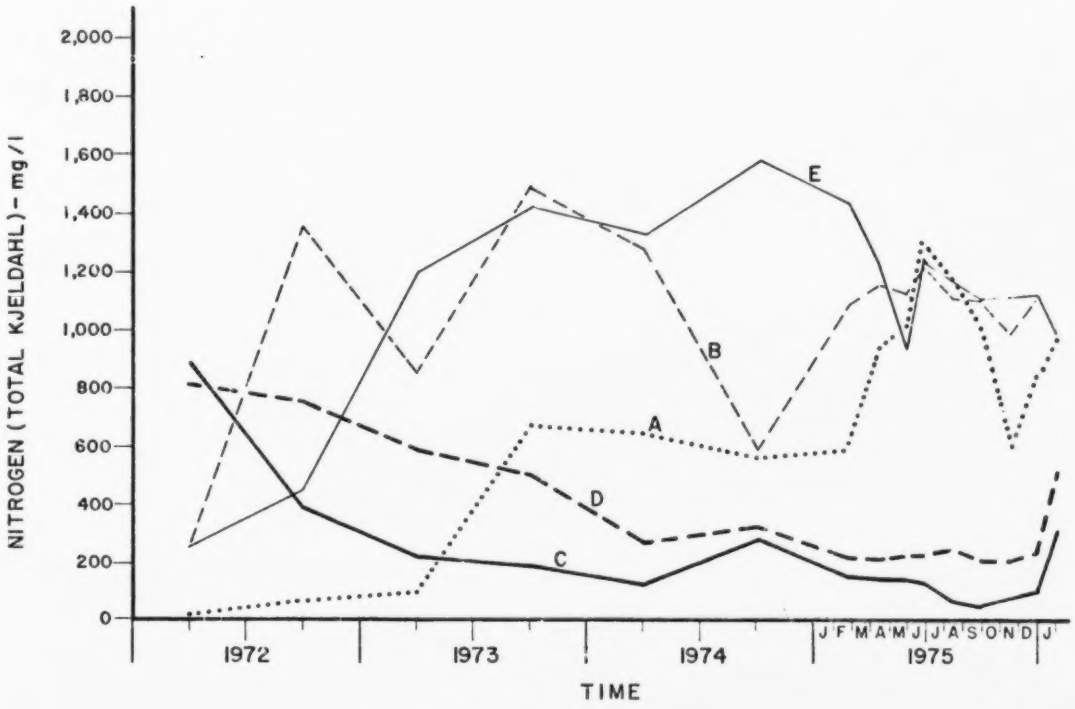


MERCURY CONCENTRATION OF LEACHATE

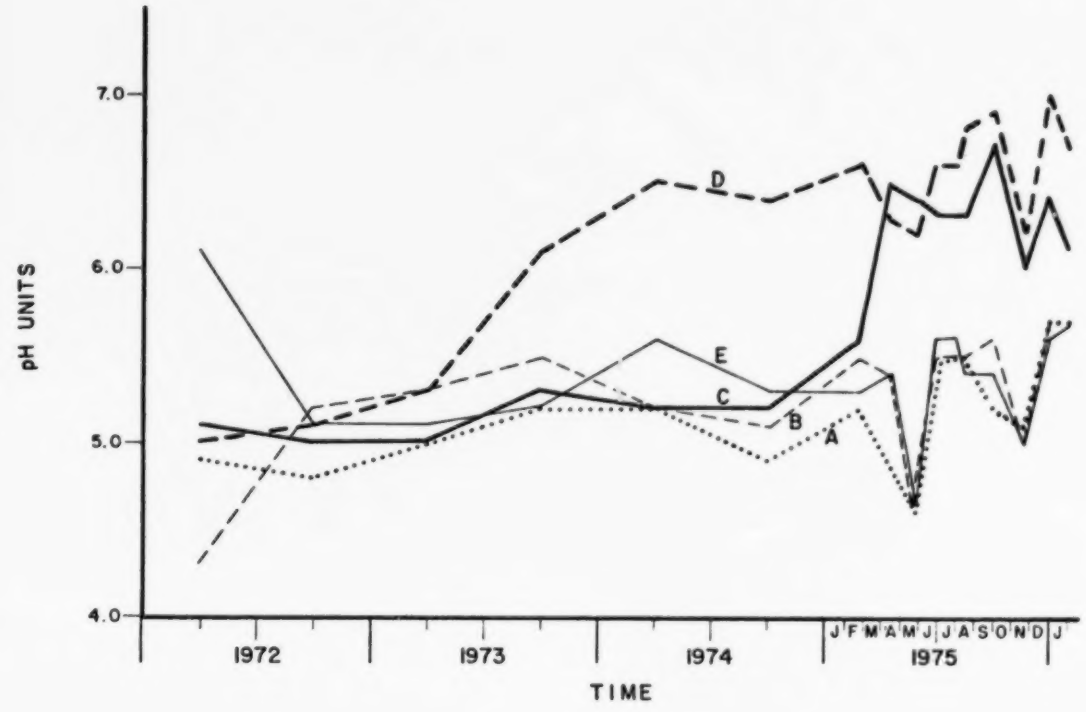
FIGURE 10



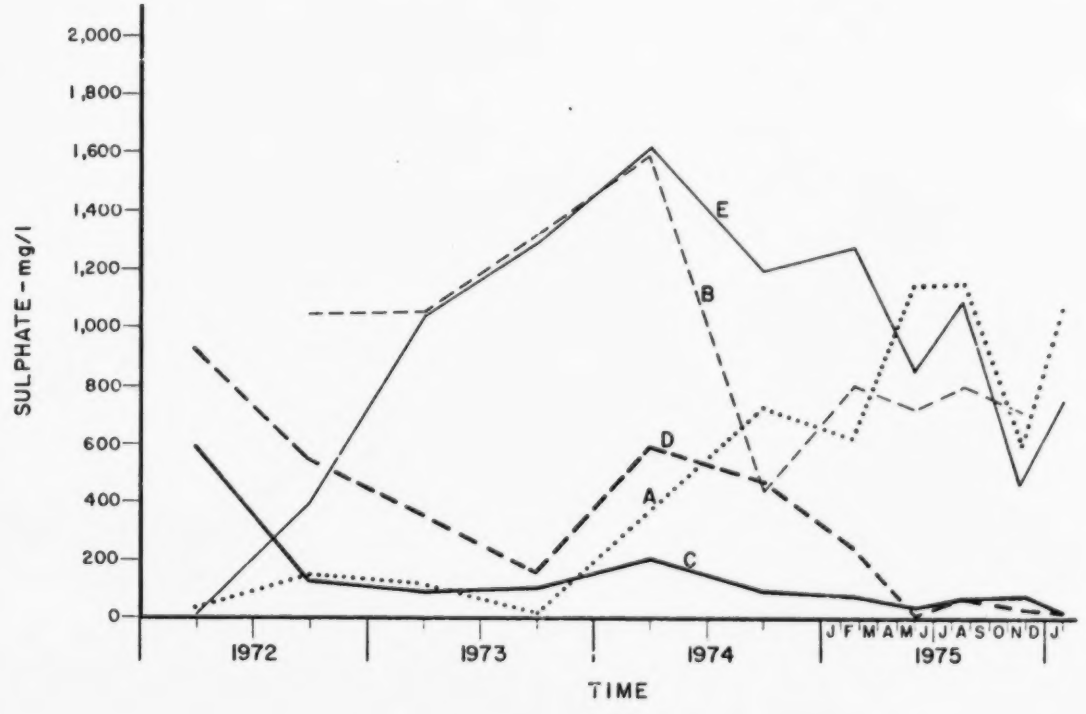
NITROGEN (NITRATE) CONCENTRATION OF LEACHATE | FIGURE 11



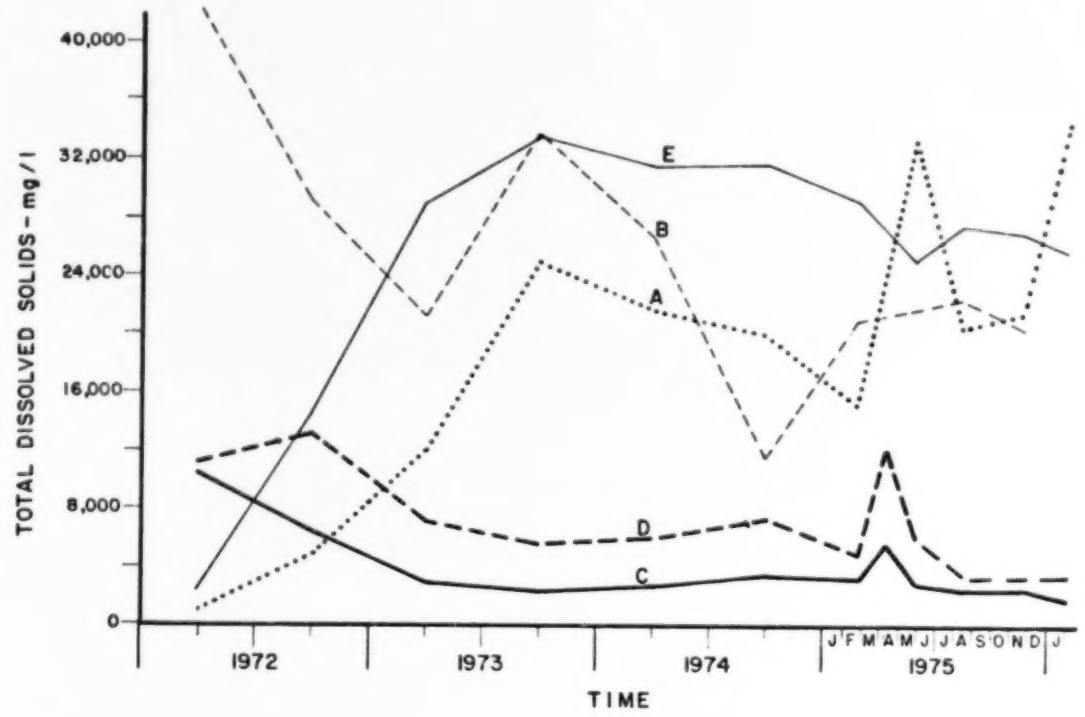
NITROGEN (TOTAL KJELDAHL) CONCENTRATION OF LEACHATE | FIGURE 12



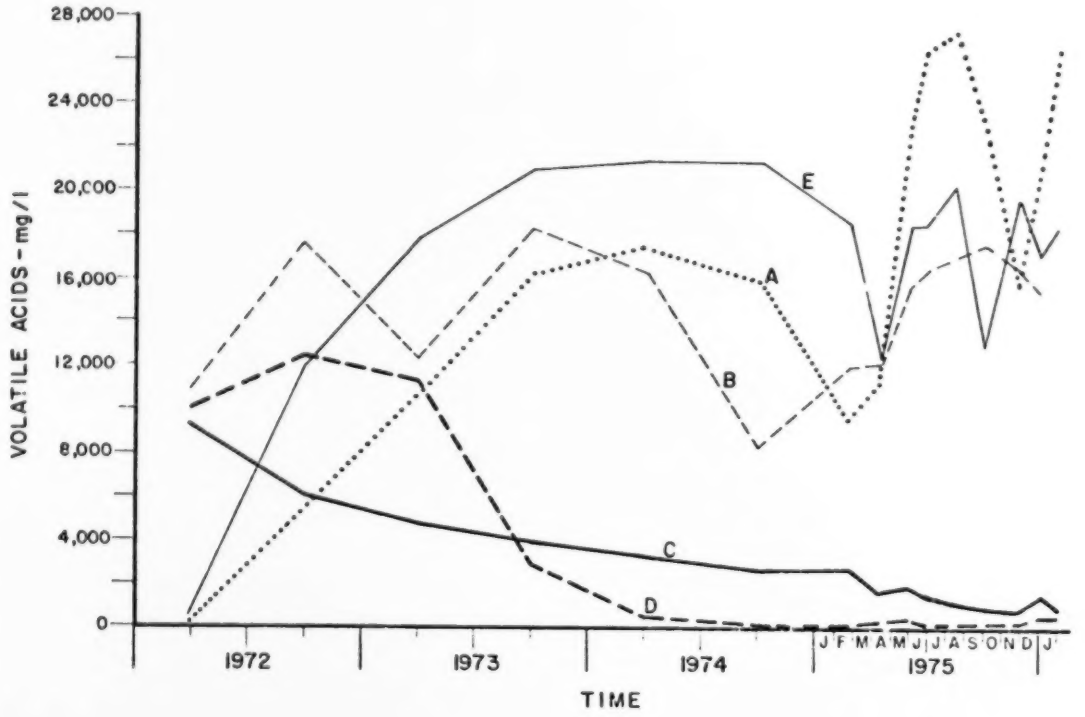
pH OF LEACHATE — FIGURE 13



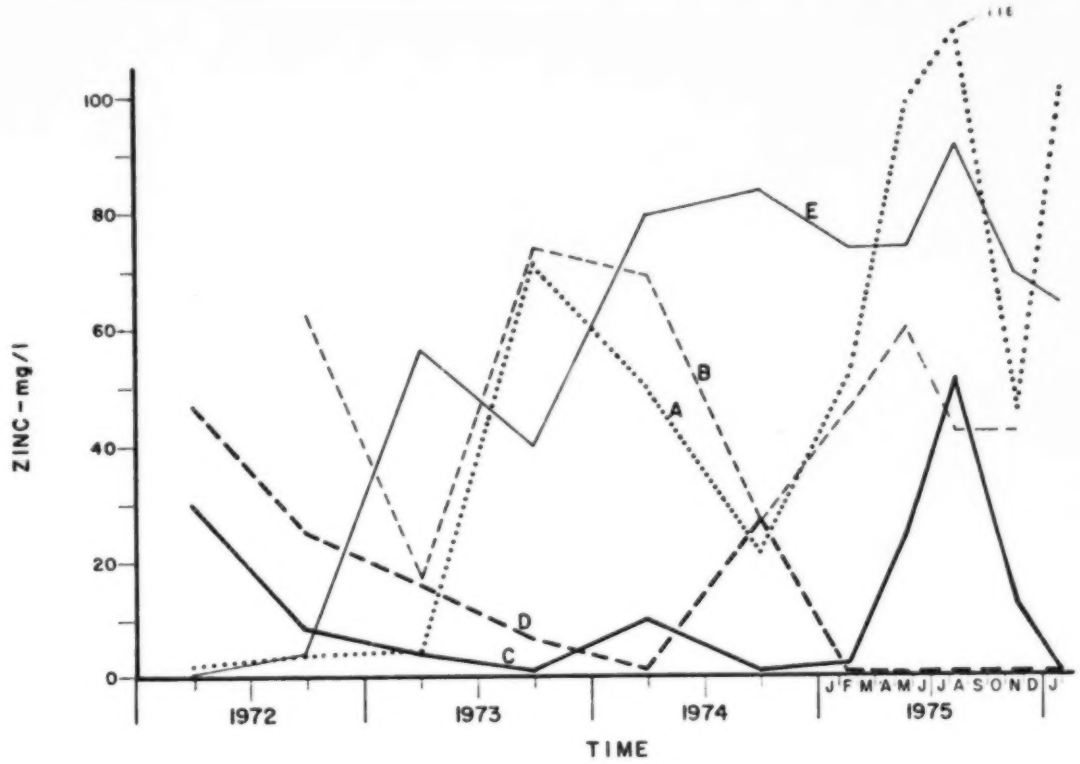
SULPHATE CONCENTRATION OF LEACHATE — FIGURE 14



TOTAL DISSOLVED SOLIDS CONCENTRATION OF LEACHATE | FIGURE 15

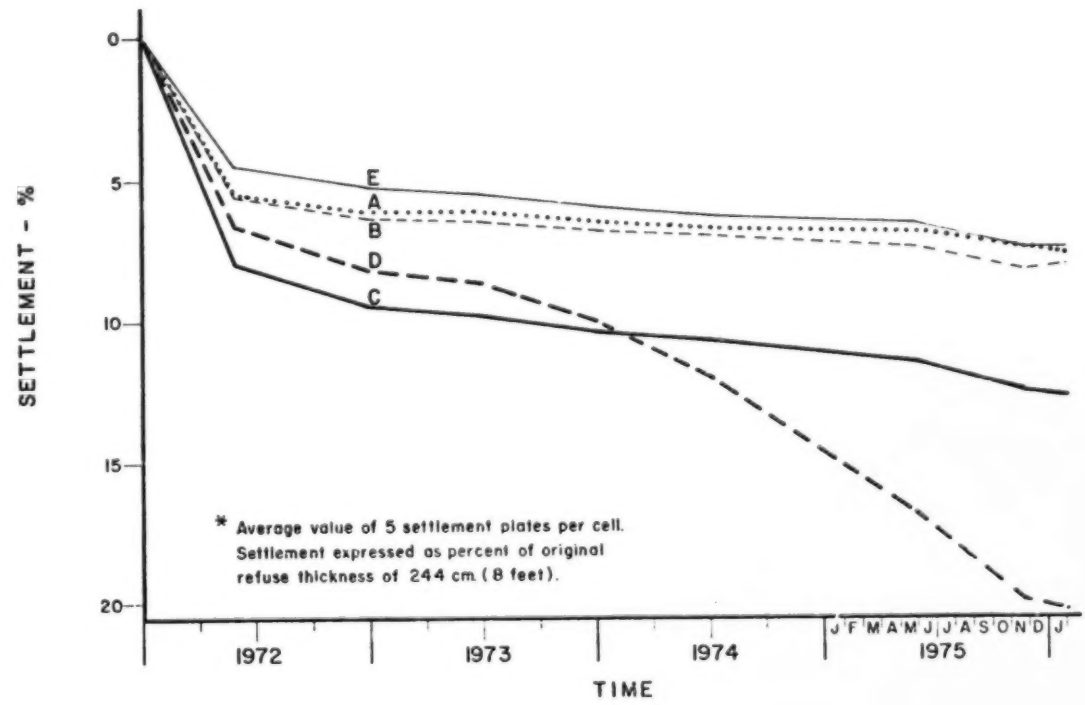


VOLATILE ACIDS CONCENTRATION OF LEACHATE | FIGURE 16



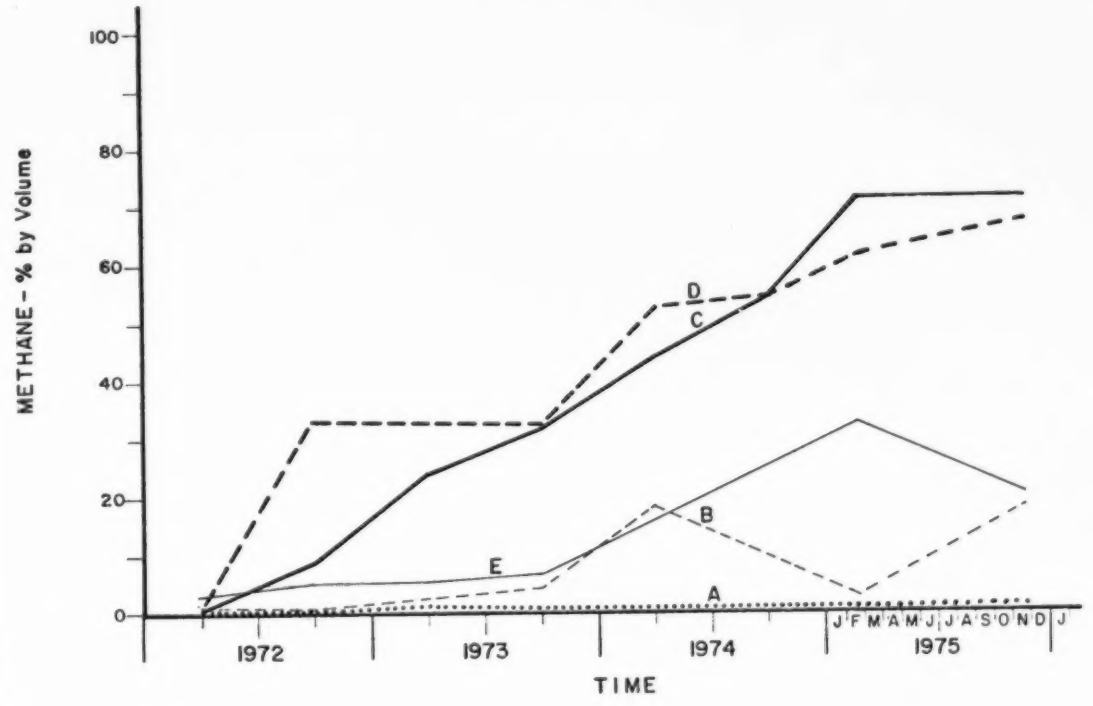
ZINC CONCENTRATION OF LEACHATE

FIGURE 17



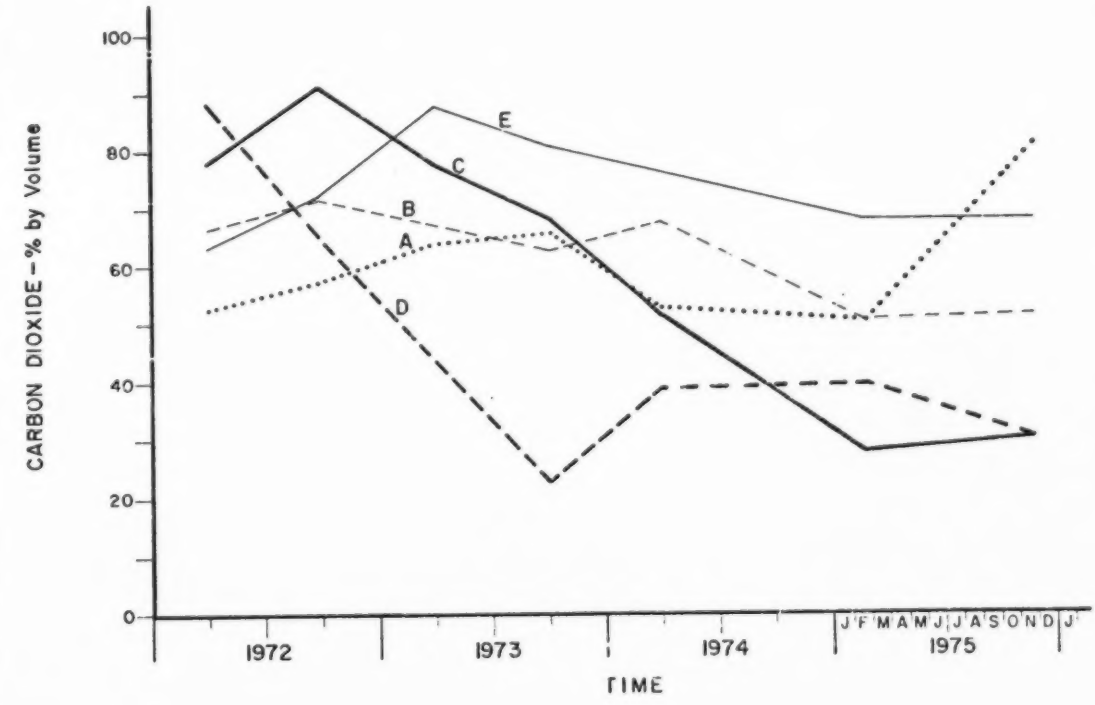
AVERAGE CELL SETTLEMENT *

FIGURE 18



METHANE CONCENTRATION OF CELL GAS

FIGURE 19



CARBON DIOXIDE CONCENTRATION OF CELL GAS

FIGURE 20

μa1381